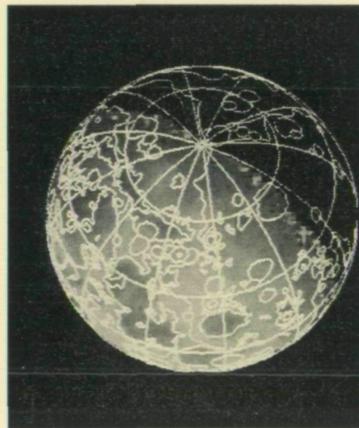
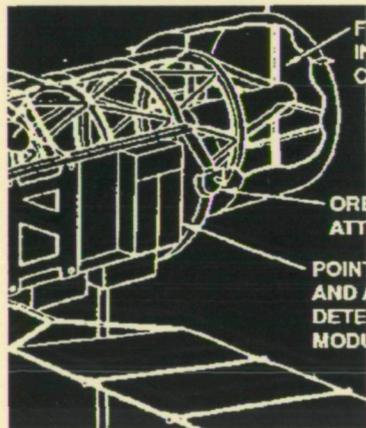
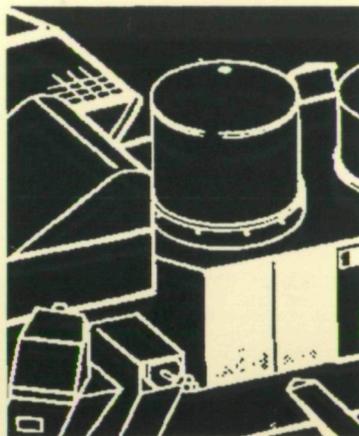
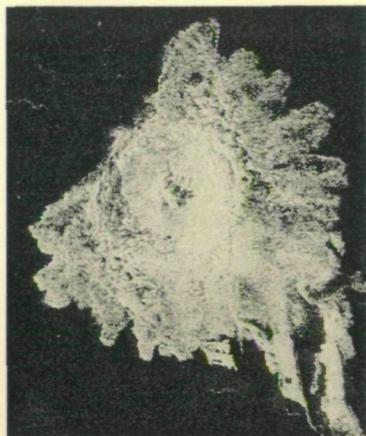


# WORKSHOP ON ADVANCED TECHNOLOGIES FOR PLANETARY INSTRUMENTS



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(NASA-CR-193015) WORKSHOP ON  
ADVANCED TECHNOLOGIES FOR PLANETARY  
INSTRUMENTS, PART 1 Abstracts Only  
(Lunar and Planetary Inst.) 46 p

G3/91 0160710

## LPI Technical Report Number 93-02, Part 1

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113  
LPI/TR--93-02, Part 1



**WORKSHOP ON  
ADVANCED TECHNOLOGIES FOR  
PLANETARY INSTRUMENTS**

Edited by

J. Appleby

Held at  
Hyatt Fair Lakes  
Fairfax, Virginia

April 28–30, 1993

Sponsored by  
NASA's Solar System Exploration Division (Office of Space Science)  
NASA's Office of Advanced Concepts and Technology  
DoD's Strategic Defense Initiative Organization  
Lunar and Planetary Institute

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113

LPI Technical Report Number 93-02, Part 1  
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Compiled in 1993 by  
LUNAR AND PLANETARY INSTITUTE

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Appleby J., ed. (1993) *Workshop on Advanced Technologies for Planetary Instruments*. LPI Tech. Rpt. 93-02, Part 1, Lunar and Planetary Institute, Houston. 28 pp.

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## Preface

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This volume contains papers presented at the Workshop on Advanced Technologies for Planetary Instruments on April 28–30, 1993, in Fairfax, Virginia. This meeting was jointly sponsored by NASA's Solar System Exploration Division (SSED), within the Office of Space Science, NASA's Office of Advanced Concepts and Technology (OACT), DoD's Strategic Defense Initiative Organization (SDIO), and the Lunar and Planetary Institute. Organizer and general chair for the workshop was John Appleby (*NASA Headquarters*). Other Program Committee members were Henry Brinton (*NASA Headquarters*), Scott Hubbard (*NASA Ames Research Center*), Stuart Nozette (*Strategic Defense Initiative Organization*), and Gregg Vane (*Jet Propulsion Laboratory*).

This meeting was conceived in response to new challenges facing NASA's robotic solar system exploration program. Missions that could go into development during the next 5 to 10 years, including Pluto Fast Flyby, MESUR Network, Discovery Program missions, and others, may require or benefit from the use of science instruments that are highly capable but low-cost, lightweight, and low-power. Over the past several years, SDIO has sponsored a significant technology development program aimed, in part, at the production of instruments with these characteristics. This workshop provided an opportunity for specialists from the planetary science and DoD communities to establish contacts, to explore common technical ground in an open forum, and more specifically, to discuss the applicability of SDIO's technology base to planetary science instruments.

Logistics and administrative and publications support were provided by the Publications and Program Services Department staff at the Lunar and Planetary Institute.

## Final Agenda

**WEDNESDAY, APRIL 28**

- 8:30 a.m.     ***Welcome and Introduction***  
Dr. John F. Appleby, **General Chair**  
Advanced Studies Branch, Solar System Exploration Division (SSED)  
Office of Space Science (OSS)
- 8:45 a.m.     ***Objectives of the Workshop***  
Dr. Wesley T. Huntress Jr.  
Associate Administrator, OSS, and Director, SSED
- 9:00 a.m.     ***Advanced Instrument Concepts***  
Mr. Samuel L. Venneri  
Director, Spacecraft and Remote Sensing Division,  
Office of Advanced Concepts and Technology (OACT)
- 9:30 a.m.     ***Strategic Defense Initiative Science and Technology Program***  
Dr. Dwight Duston  
Director, Innovative Science and Technology  
Strategic Defense Initiative Organization (SDIO)
- 9:45 a.m.     ***Solar System Exploration During the Next Five to Ten Years***  
Dr. Carl B. Pilcher  
Chief, Advanced Studies Branch, SSED
- 10:05 a.m.    ***Selection and Development of SSED Science Instruments***  
Mr. Henry C. Brinton  
Chief, Planetary Science Branch, SSED
- 10:25 a.m.    **BREAK**

### **PLUTO FAST FLYBY MISSION**

Moderator: H. Reitsema, Ball Aerospace

- 10:40 a.m.    ***Current Baseline Mission, Science and Measurement Objectives, and Strawman Instrument Payload***  
A. Stern, Southwest Research Institute  
Chair, SSED's Outer Planets Science Working Group
- 11:00 a.m.    ***Visible Imaging System***  
M. Malin, Malin Space Systems, Inc.

11:20 a.m. *Infrared Mapping Spectrometer*  
R. Brown, Jet Propulsion Laboratory

11:40 a.m. *Ultraviolet Spectrometer*  
W. McClintock, University of Colorado

12:00 noon LUNCH

**MARS ENVIRONMENTAL SURVEY (MESUR) MISSION**

Moderator: M. Tomasko, University of Arizona

1:00 p.m. *Current Baseline Mission, Science and Measurement Objectives, and Strawman Instrument Payload*  
S. Squyres, Cornell University  
Chair, SSED's MESUR Science Definition Team

1:20 p.m. *Visible Imager*  
E. Danielson, California Institute of Technology

1:40 p.m. *Micro-Meteorological Package*  
W. Kaiser and D. Crisp, Jet Propulsion Laboratory

2:00 p.m. *Alpha-Proton-X-ray ( $\alpha$ -p-x) Spectrometer*  
T. Economou, University of Chicago

2:20 p.m. *Micro-Seismometer*  
B. Banerdt, Jet Propulsion Laboratory

2:40 p.m. *Thermal Analyzer/Evolved Gas Analyzer (TA/EGA)*  
W. Boynton, University of Arizona

3:00 p.m. BREAK

**MISSIONS TO SMALL BODIES (ASTEROIDS AND COMETS)**

Moderator: P. Feldman, Johns Hopkins University

3:20 p.m. *Current Mission Concepts, Scientific and Measurement Objectives*  
M. Neugebauer, JPL

3:40 p.m. *Remote Sensing Science*  
J. Veverka, Cornell University  
Chair, SSED's Small Bodies Science Working Group

4:00 p.m. *In Situ Measurements*  
W. Boynton, University of Arizona

- 4:20 p.m. *Lunar Science: Using the Moon as a Testbed*  
G. J. Taylor, University of Hawaii  
Chair, SSED's Lunar Exploration Science Working Group
- 4:40 p.m. *Mars '94 Occident Experiment*  
A. Lane, JPL
- 4:50 p.m. *Planetary Instrumentation: Closing Comments*  
S. Hubbard, NASA Ames Research Center (ARC)
- 5:00 p.m. POSTER SESSION with Wine and Cheese Social (contributed posters are listed at the end of the agenda)
- 6:30 p.m. ADJOURN FOR THE DAY

|                           |
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| <b>THURSDAY, APRIL 29</b> |
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**SDIO-DEVELOPED INSTRUMENT TECHNOLOGY WITH  
POTENTIAL APPLICATION TO PLANETARY EXPLORATION**

- 8:30 a.m. *Introduction and Overview*  
D. Duston, SDIO

**PASSIVE REMOTE SENSING**

Moderator: D. Duston

- 8:50 a.m. *Ultraviolet Plume Image Experiment*  
D. Horan, Naval Research Laboratory (NRL)
- 9:10 a.m. *Advanced UV Sensors*  
D. Duston, SDIO
- 9:30 a.m. *Clementine Mission: UV/Visible Camera*  
L. Pleasance, Lawrence Livermore National Laboratory (LLNL)
- 9:50 a.m. *Clementine Mission: Lightweight IR Camera and Multi-Spectral Approaches*  
A. Ledebuhr, LLNL
- 10:20 a.m. BREAK
- 10:40 a.m. *MSTI (Miniature Seeker Technology Integration) Mission*  
R. Matlock, SDIO
- 11:00 a.m. *Interceptor Sensors*  
W. Fredrick, SDIO
- 11:20 a.m. *Clementine Mission: Long-Wavelength IR Camera*  
I. Lewis, LLNL

## ACTIVE REMOTE SENSING

- 11:40 a.m. *Lightweight Lidar*  
D. Holtkamp, SDIO
- 12:00 noon LUNCH
- 1:00 p.m. *Neutral Particle Beam Sensing: Proposed U.S./Russian Experiment*  
M. Nikolich, SDIO  
R. Joseph, Los Alamos National Laboratory (LANL)

## PROCESSING SYSTEMS FOR SENSOR DATA

- 1:20 p.m. *Clementine Sensor Processing System*  
A. Feldstein, NRL
- 1:40 p.m. *Advanced Sensor Processing System Architectures*  
L. Pleasance and R. Peterson, LLNL
- 2:00 p.m. *Advanced Data Processing*  
S. Larimore, SDIO

## PHENOMENOLOGY AND BACKGROUND EXPERIMENTS

- 2:20 p.m. *MSX (Mid-Course Sensor Experiment)*  
B. Tilton, SDIO  
TBD, Applied Physics Laboratory (APL), Johns Hopkins University
- 2:50 p.m. *SDIO Instrumentation: Closing Comments*  
D. Duston, SDIO
- 3:00 p.m. BREAK
- 3:20 p.m. **INFORMAL WORKING GROUP MEETINGS, POSTER SESSION CONTINUES**  
W/G 1: UV-Visible Remote Sensing Chair: A. Lane, JPL  
W/G 2: IR Remote Sensing Chair: E. Heighway  
W/G 3: Data Processing Chair: L. Pleasance, LLNL  
W/G 4: *In Situ* Measurements Chair: W. Boynton, University of Arizona
- 5:30 p.m. ADJOURN FOR THE DAY

|                         |
|-------------------------|
| <b>FRIDAY, APRIL 30</b> |
|-------------------------|

## **WORKING GROUP REPORTS AND PANEL DISCUSSION**

Moderator: S. Hubbard, NASA Ames Research Center

- 8:30 a.m. Working Group 1: UV-Visible Remote Sensing  
Chair: A. Lane, JPL
- 9:00 a.m. Working Group 2: IR Remote Sensing  
Chair: E. Heighway
- 9:30 a.m. Working Group 3: Data Processing  
Chair: L. Pleasance, LLNL
- 10:00 a.m. Working Group 4: *In Situ* Measurements  
Chair: W. Boynton, University of Arizona
- 10:30 a.m.. **BREAK**
- 10:45 a.m. ***Panel Discussion: Conclusions and Recommendations***  
H. Brinton, NASA, SSED  
S. Venneri, NASA, OACT  
D. Duston, SDIO  
L. Pleasance, Lawrence Livermore National Laboratory  
G. Vane, Jet Propulsion Laboratory  
R. Capps, Jet Propulsion Laboratory  
B. Wilson, Jet Propulsion Laboratory  
A. Delamere, Ball Aerospace Corp.  
T. Knight, Martin Marietta Corp.  
H. Plotkin, NASA Goddard Space Flight Center  
T. Krimigis, Applies Physics Lab, Johns Hopkins University
- 11:45 a.m. ***Workshop Summary Documentation***  
A. Lane, Jet Propulsion Laboratory
- 12:00 p.m. **WORKSHOP ADJOURNS**

## CONTRIBUTED POSTERS

*The HYDICE Instrument Design and Its Application to Planetary Instruments*

R. Basedow, P. Silverglate, W. Rappoport, R. Rockwell, D. Rosenberg, K. Shu, R. Whittlesey, and E. Zalewski

*Rugged, No-Moving-Parts Windspeed and Static Pressure Probe Designs for Measurements in Planetary Atmospheres*

A. J. Bedard Jr. and R. T. Nishiyama

*Design of a Particle Beam Satellite System for Lunar Prospecting*

D. H. Berwald and P. Nordin

*Laser-induced Breakdown Spectroscopy Instrument for Elemental Analysis of Planetary Surfaces*

J. Blacic, D. Pettit, D. Cremers, and N. Roessler

*Clementine II: A Double Asteroid Flyby and Impactor Mission*

R. J. Boain

*High-Performance Visible/UV CCD Focal Plane Technology for Spacebased Applications*

B. E. Burke, R. W. Mountain, J. A. Gregory, J. C. M. Huang, M. J. Cooper, E. D. Savoye, and B. B. Kosicki

*Every Good Virtue You Ever Wanted in a Q-switched Solid-State Laser and More—Monolithic, Diode-pumped, Self-Q-switched, Highly Reproducible, Diffraction-limited Nd:YAG Laser*

Y. C. Chen and K. K. Lee

*Planetary and Satellite X-Ray Spectroscopy: A New Window on Solid-Body Composition by Remote Sensing*

D. L. Chenette, R. W. Wolcott, and R. S. Selesnick

*Polarimetric Multispectral Imaging Technology*

L.-J. Cheng, T.-H. Chao, M. Dowdy, C. Mahoney, and G. Reyes

*A Remote Laser-Mass Spectrometer for Determination of Elemental Composition*

R. J. De Young and W. Situ

*Investigation of Mars Rotational Dynamics Using Earth-based Radio Tracking of Mars Landers*

C. D. Edwards Jr., W. M. Folkner, R. D. Kahn, and R. A. Preston

*Design Concept for an IR Mapping Spectrometer for the Pluto Fast Flyby Mission*

U. Fink, F. Low, B. Hubbard, M. Rieke, G. Rieke, M. Mumma, S. Nozette, G. Neukum, H. Hamel, M. DiSanti, M. Buie, and A. Hoffman

*Multibeam Laser Altimeter for Planetary Topographic Mapping*

J. B. Garvin, J. L. Bufton, and D. J. Harding

*Acousto-Optic Infrared Spectral Imager for Pluto Fast Flyby*

D. A. Glenar and J. J. Hillman

*Thermal Analyzer for Planetary Soils (TAPS): An In Situ Instrument for Mineral and Volatile-Element Measurements*

J. L. Gooding, D. W. Ming, J. E. Gruener, F. L. Gibbons, and J. H. Allton

*Imaging Spectrometers Using Concave Holographic Gratings*

J. Gradie and S. Wang

*The Atmospheric Ultraviolet Radiance Integrated Code (AURIC) Validation of Version 1.0*

R. E. Huffman, J. Zdyb, R. Link, and D. J. Strickland

*Microtextured Metals for Stray-Light Suppression in the Clementine Startracker*

E. A. Johnson

*New Technologies for UV Detectors*

C. L. Joseph

*Lightweight Modular Instrumentation for Planetary Applications*

P. B. Joshi

*Optical Technologies for UV Remote Sensing Instruments*

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*Multiscale Morphological Filtering for Analysis of Noisy and Complex Images*

A. Kher and S. Mitra

*A Unique Photon Bombardment System for Space Applications*

E. J. Klein

*Detection of Other Planetary Systems Using Photometry*

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*An Integrated XRF/XRD Instrument for Mars Exobiology and Geology Experiments*

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*A DTA/GC for the In Situ Identification of the Martian Surface Material*  
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*Onboard Signal Processing: Wave of the Future for Planetary Radio Science?*  
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## Abstracts

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**A MICROSEISMOMETER FOR TERRESTRIAL AND EXTRATERRESTRIAL APPLICATIONS.** W. Banerdt, W. Kaiser, and T. Van Zandt, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

The scientific and technical requirements of extraterrestrial seismology place severe demands on instrumentation. Performance in terms of sensitivity, stability, and frequency band must match that of the best terrestrial instruments, at a fraction of the size, mass, and power. In addition, this performance must be realized without operator intervention in harsh temperature, shock, and radiation environments. These constraints have forced us to examine some fundamental limits of accelerometer design in order to produce a small, rugged, sensitive seismometer.

Silicon micromachined sensor technology offers techniques for the fabrication of monolithic, robust, compact, low-power and -mass accelerometers [1]. However, currently available sensors offer inadequate sensitivity and bandwidth. Our implementation of an advanced silicon micromachined seismometer is based on principles developed at JPL for high-sensitivity position sensor technology. The use of silicon micromachining technology with these new principles should enable the fabrication of a  $10^{-11}$  g sensitivity seismometer with a bandwidth of at least 0.01 to 20 Hz. The low Q properties of pure single-crystal silicon are essential in order to minimize the Brownian thermal noise limitations generally characteristic of seismometers with small proof masses [2].

A seismometer consists of a spring-supported proof mass (with damping) and a transducer for measuring its motion. For long-period motion a position sensor is generally used, for which the displacement is proportional to the ground acceleration. The mechanical sensitivity can be increased either by increasing the proof mass or decreasing the spring stiffness, neither of which is desirable for planetary applications. Our approach has been to use an ultra-sensitive capacitive position sensor with a sensitivity of better than  $10^{-13}$  m/Hz<sup>1/2</sup>. This allows the use of a stiffer suspension (leading to a wider operating bandwidth and insensitivity to physical shock) and a smaller proof mass (allowing lower instrument mass).

We have built several prototypes using these principles, and tests show that these devices can exhibit performance comparable to state-of-the-art instruments. The total volume of the final seismometer sensor is expected to be a few tens of cubic centimeters, with a total mass and power consumption of approximately 100 g and 100 mW.

**References:** [1] Petersen K. E. (1982) *Proc. IEEE*, 70, 420. [2] Melton B. S. (1976) *Rev. Geophys. Space Phys.*, 14, 93.

**THE HYDICE INSTRUMENT DESIGN AND ITS APPLICATION TO PLANETARY INSTRUMENTS.** R. Basedow, P. Silvergate, W. Rappoport, R. Rockwell, D. Rosenberg, K. Shu, R. Whittlesey, and E. Zalewski, Hughes Danbury Optical Systems, Inc., Danbury CT 06810-7589, USA.

The Hyperspectral Digital Imagery Collection Experiment

(HYDICE) instrument represents a significant advance in the state of the art in hyperspectral sensors. It combines a higher signal-to-noise ratio (SNR) and significantly better spatial and spectral resolution and radiometric accuracy than systems flying on aircraft today. The need for "clean" data, i.e., data free of sampling artifacts and excessive spatial or spectral noise, is a key driver behind the difficult combination of performance requirements laid out for HYDICE. Most of these involve the sensor optics and detector. This paper presents an optimized approach to those requirements, one that comprises pushbroom scanning, a single, mechanically cooled focal plane, a double-pass prism spectrometer, and an easily fabricated yet wide-field telescope. Central to the approach is a detector array that covers the entire spectrum from 0.4 to 2.5  $\mu$ m. Among the major benefits conferred by such a design are optical and mechanical simplicity, low polarization sensitivity, and coverage of the entire spectrum without suffering the spectral gaps caused by beamsplitters. The overall system minimizes interfaces to the C141 aircraft on which it will be flown, can be calibrated on the ground and in flight to accuracies better than those required, and is designed for simple, push-button operation. Only unprocessed data are recorded during flight. A ground data processing station provides quick-look, calibration correction and archiving capabilities, with a throughput better than the requirements. Overall performance of the system is expected to provide the solid database required to evaluate the potential of hyperspectral imagery in a wide variety of applications.

HYDICE can be regarded as a testbed for future planetary instruments. The ability to spectrally image a wide field of view over multiple spectral octaves offers obvious advantages, and is expected to maximize science return for the required cost and weight.

**RUGGED, NO-MOVING-PARTS WINDSPEED AND STATIC PRESSURE PROBE DESIGNS FOR MEASUREMENTS IN PLANETARY ATMOSPHERES.** A. J. Bedard Jr.<sup>1</sup> and R. T. Nishiyama<sup>2</sup>, <sup>1</sup>NOAA/ERL/Wave Propagation Laboratory, Boulder CO 80303, USA, <sup>2</sup>Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado/NOAA, Boulder CO 80309, USA.

Instruments developed for making meteorological observations under adverse conditions on Earth can be applied to systems designed for other planetary atmospheres. Specifically, a wind sensor developed for making measurements within tornados [1] has no moving parts, detecting induced pressure differences proportional to wind speed. Addition of strain gauges to the sensor would provide wind direction. The device can be constructed in a rugged form for measuring high wind speeds in the presence of blowing dust that would clog bearings and plug passages of conventional wind speed sensors.

Sensing static pressure in the lower boundary layer required development of an omnidirectional, tilt-insensitive static pressure probe [2]. The probe provides pressure inputs to a sensor with minimum error and is inherently weather-protected. Both the wind

sensor and static pressure probes have been applied in a variety of field programs and can be adapted for use in different planetary atmospheres.

**References:** [1] Bedard A. J. Jr. and Ramsey C. (1988) *J. Appl. Meteor.*, 22, 911-918. [2] Nishiyama R. T. and Bedard A. J. Jr. (1991) *Rev. Sci. Instr.*, 62, 2143-2204.

5 N-93-28768 P-1  
**DESIGN OF A PARTICLE BEAM SATELLITE SYSTEM FOR LUNAR PROSPECTING.** D. H. Berwald and P. Nordin, Grumman Aerospace and Electronics, Bethpage NY 11714, USA.

One potential use for neutral particle beam (NPB) technology is as an active orbital probe to investigate the composition of selected locations on the lunar surface. Because the beam is narrow and can be precisely directed, the NPB probe offers possibilities for high-resolution experiments that cannot be accomplished using passive techniques. Rather, the combination of both passive and active techniques can be used to provide both full-coverage mapping (passively) at low resolution (tens of kilometers) and high-resolution information for discrete locations of special interest.

A preliminary study of NPB applicability for this dual-use application was recently conducted by Grumman and its subcontractors, McDonnell Douglas and SAIC. This study was completed in February 1993 [1]. A novel feature was that consideration of the use of a Russian launch vehicle (e.g., the Proton) and other Russian space hardware and capabilities was encouraged. This paper describes the lunar prospector system design. Toepfer et al. [2] discuss issues and opportunities involving lunar scientific experimentation using an NPB.

The NPB lunar prospector utilizes a modified design of the Far Field Optics Experiment (FOX) [3]. Like the Earth-orbiting FOX, the core capability of the NPB lunar prospector will be a pulsed RF LINAC that produces a 5-MeV proton beam that is projected to the target with a 30- $\mu$ r beam divergence and a 10- $\mu$ r beam-pointing accuracy. Upon striking the lunar surface, the proton beam will

excite characteristic radiation (e.g., X-rays) that can be sensed by one or more detectors on the NPB platform or on a separate detector satellite.

Two principal design variants have emerged. The first, a non-nuclear design, utilizes a Proton fourth stage for transfer to lunar orbit. The electric power source is solar and the NPB satellite performs its experimental program while orbiting about 50 km above the lunar surface. When the NPB satellite passes over its target, the beam is activated and the experiment is performed. A key issue for this configuration is the design mass margin that can be achieved within the capabilities of the Proton fourth stage.

The second design variant is powered by a Topaz 3 nuclear reactor (40 KWe). Efficient but low-thrust electric propulsion (e.g., SPT-200 or larger) is used for orbital transfer. The payload delivered to lunar orbit is much larger, but a second spacecraft will be required to provide adequate separation of the nuclear reactor and the detector. A high-low configuration is employed. The detector and NPB orbit at altitudes of 25-50 km and 1980 km respectively. The issues for the second design are technology availability, reliability, and cost.

This work was supported by the U.S. Army Space and Strategic Defense Command under Contract No. DASG60-90-C-0103.

**References:** [1] Grumman Aerospace (1993) *Final Report, NPBE Special Study Task 4*. [2] Toepfer A. J. et al. (1993), this volume. [3] Grumman Aerospace (1992) *Final Report, NPBE Basic Contract Task 1*.

N-93-28769 P-2  
**LASER-INDUCED BREAKDOWN SPECTROSCOPY INSTRUMENT FOR ELEMENTAL ANALYSIS OF PLANETARY SURFACES.** J. Blacic<sup>1</sup>, D. Pettit<sup>1</sup>, D. Cremers<sup>2</sup>, and N. Roessler<sup>3</sup>, <sup>1</sup>Geology and Geochemistry Group, Los Alamos National Laboratory, Los Alamos NM 87545, USA, <sup>2</sup>Photochemistry and Photophysics Group, Los Alamos National Laboratory, Los Alamos NM 87545, USA, <sup>3</sup>McDonnell Douglas Electronics Systems Co., St. Louis MO 63166, USA.

TABLE 1. Systems analysis summary for LIBS instrument.

| Systems: | Diode-Pumped, Nd-YAG Laser System* |                              |                        | Spectrometer System <sup>†</sup> |           | Optical System | Support System <sup>‡</sup> |           | Total Instrument <sup>§</sup> |           |
|----------|------------------------------------|------------------------------|------------------------|----------------------------------|-----------|----------------|-----------------------------|-----------|-------------------------------|-----------|
|          | Optical Energy (mJ)                | Average Electrical Power*(W) | Mass <sup>†</sup> (kg) | Mass (kg)                        | Power (W) | Mass (kg)      | Mass (kg)                   | Power (W) | Mass (kg)                     | Power (W) |
| 20-40    | 180                                | 0.3                          | 0.7                    | 2.0                              | 3.2       | 0.3            | 0.5                         | 0.4       | 3.5                           | 3.9       |
| 50-100   | 320                                | 0.6                          | 4.8                    | 2.0                              | 3.2       | 0.5            | 0.8                         | 0.6       | 8.1                           | 4.4       |
| 100-500  | 1000                               | 1.5                          | 16                     | 2.0                              | 3.2       | 0.8            | 1.8                         | 0.8       | 20.6                          | 5.5       |

\*Assumes 10-ns pulse and 0.1-Hz repetition rate (McDonnell Douglas Electronic Systems Co.).

<sup>†</sup> Includes power conditioning and storage.

<sup>‡</sup> Includes spectrograph, intensified CCD detector, thermoelectric cooler, and electronics.

<sup>§</sup> Includes structure, motors, and misc. hardware.

<sup>¶</sup> No power generation or communications allowance.

One of the most fundamental pieces of information about any planetary body is the elemental and mineralogical composition of its surface materials. We are developing an instrument to obtain such data at ranges of up to several hundreds of meters using the technique of Laser-Induced Breakdown Spectroscopy, or LIBS. We envision our instrument being used from a spacecraft in close rendezvous with small bodies such as comets and asteroids, or deployed on surface-rover vehicles on large bodies such as Mars and the Moon. The elemental analysis is based on atomic emission spectroscopy of a laser-induced plasma or spark. A pulsed, diode-pumped Nd:YAG laser of several hundred millijoules optical energy is used to vaporize and electronically excite the constituent elements of a rock surface remotely located from the laser. Light emitted from the excited plasma is collected and introduced to the entrance slit of a small grating spectrometer. The spectrally dispersed spark light is detected with either a linear photo diode array or area CCD array. When the latter detector is used, the optical and spectrometer components of the LIBS instrument can also be used in a passive imaging mode to collect and integrate reflected sunlight from the same rock surface. Absorption spectral analysis of this reflected light gives mineralogical information that, when combined with the elemental analysis from the LIBS mode, provides a complete remote geochemical characterization of the rock surface.

We have performed laboratory calibrations in air and in vacuum on standard rock powders to quantify the LIBS analysis. We have performed preliminary field tests using commercially available components to demonstrate remote LIBS analysis of terrestrial rock surfaces at ranges of over 25 m, and we have demonstrated compatibility with a six-wheeled Russian robotic rover vehicle. Based on these results, we believe that all major and most minor elements expected on planetary surfaces can be measured with absolute accuracy of 10–15% and much higher relative accuracy. We have performed preliminary systems analysis of a LIBS instrument to evaluate probable mass and power requirements; results of this analysis are summarized in Table 1.

**N93-28771 0160716 P. 1**  
**CLEMENTINE II: A DOUBLE ASTEROID FLYBY AND IMPACTOR MISSION.** R. J. Boain, Jet Propulsion Laboratory, Pasadena CA 91109, USA.

Recently JPL was asked by SDIO to analyze and develop a preliminary design for a deep-space mission to fly by two near-Earth asteroids, Eros and Toutatis. As a part of this mission, JPL was also asked to assess the feasibility of deploying a probe on approach to impact Toutatis. This mission is a candidate for SDIO's Clementine II.

SDIO's motivations were to provide further demonstrations of precision, autonomous navigation for controlling the flight paths of both a spacecraft and a probe. NASA's interest in this mission is driven by the opportunity to obtain the first close-up images and other scientific measurements from a spacecraft of two important near-Earth objects. For Toutatis this is especially important since it was observed and imaged extensively just last December using Earth-based radar; Clementine II will provide the opportunity to corroborate the radar data and validate the ultimate potential of the

radar technique.

Scientifically, the probe impact at Toutatis will allow the acquisition of data pertaining to the dynamic strength of surface material and data on the properties of the regolith and on stratification below the surface, and will potentially allow the measurement of thermal diffusivity between the interior and the surface. These determinations will be accomplished by means of high-resolution imagery of the impact crater and its surroundings in visible, ultraviolet, and infrared wavebands from the spacecraft flying by some 30 min after the probe strike. In addition, if the spacecraft can be equipped with a lightweight mass spectrometer and dust analyzer, the potential also exists to measure the particle sizes and distribution and the composition of the ejecta cloud.

This mission is planned to be launched in July 1995, with the Eros encounter on March 13, 1996, and the Toutatis flyby on October 4, 1996, some 440 days after launch. The Eros encounter is characterized by a flyby speed of 8.4 km/s and a Sun-target-spacecraft phase angle of 120°. Thus, the principal visible light images of Eros will be obtained after closest approach. The Eros miss distance is nominally set at 30 km. For Toutatis, the encounter is characterized by an approach speed of 17.8 km/s and a phase angle of 20°. With this approach geometry, Toutatis presents a sunlit face to the spacecraft and probe. The probe will hit the asteroid at approximately 18 km/s. To facilitate imagery of the impact crater and to assure continuous line-of-sight tracking through encounter, the closest approach distance at Toutatis is selected to be 50.0 km.

**N93-28771 160717 P. 2**  
**HIGH-PERFORMANCE VISIBLE/UV CCD FOCAL PLANE TECHNOLOGY FOR SPACEBASED APPLICATIONS.** B. E. Burke, R. W. Mountain, J. A. Gregory, J. C. M. Huang, M. J. Cooper, E. D. Savoye, and B. B. Kosicki, Lincoln Laboratory, Massachusetts Institute of Technology, P.O. Box 73, Lexington MA 02173-9108, USA.

We describe recent technology developments aimed at large CCD imagers for spacebased applications in the visible and UV. Some of the principal areas of effort include work on reducing device degradation in the natural space-radiation environment, improvements in quantum efficiency in the visible and UV, and larger-device formats. One of the most serious hazards for space-based CCDs operating at low signal levels is the displacement damage resulting from bombardment by energetic protons. Such damage degrades charge-transfer efficiency and increases dark current. We have achieved improved hardness to proton-induced displacement damage by selective ion implants into the CCD channel and by reduced temperature of operation. To attain high quantum efficiency across the visible and UV we have developed a technology for back-illuminated CCDs. With suitable antireflection (AR) coatings such devices have quantum efficiencies near 90% in the 500–700-nm band. In the UV band from 200 to 400 nm, where it is difficult to find coatings that are sufficiently transparent and can provide good matching to the high refractive index of silicon, we have been able to substantially increase the quantum efficiency using a thin film of HfO<sub>2</sub> as an AR coating. These technology efforts have been applied to a 420 × 420-pixel frame-transfer imager, and

future work will be extended to a 1024 x 1024-pixel device now under development.

This work was sponsored by the Department of the Air Force.

5N93-2877260718

**EVERY GOOD VIRTUE YOU EVER WANTED IN A Q-SWITCHED SOLID-STATE LASER AND MORE—MONOLITHIC, DIODE-PUMPED, SELF-Q-SWITCHED, HIGHLY REPRODUCIBLE, DIFFRACTION-LIMITED Nd:YAG LASER.** Y. C. Chen<sup>1</sup> and K. K. Lee<sup>2</sup>, <sup>1</sup>Physics Department, Hunter College of CUNY, New York NY 10021, USA, <sup>2</sup>Electrical and Computer Engineering Department, University of Colorado, Colorado Springs CO 80933-7150, USA.

The applications of Q-switched lasers are well known, for example, laser radar, laser remote sensing, satellite orbit determination, Moon orbit and "moonquake" determination, satellite laser communication, and many nonlinear optics experiments. Most of the applications require additional properties of the Q-switched lasers, such as single-axial and/or single-transverse mode, high repetition rate, stable pulse shape and pulse width, or ultracompact and rugged oscillators with some or all of the above properties. Furthermore, spacebased and airborne lasers for lidar and laser communication applications require efficient, compact, lightweight, long-lived, stable-pulsed laser sources. Diode-pumped solid-state lasers (DPSSL) have recently shown the potential of satisfying all these requirements.

We will report the operating characteristics of a diode-pumped monolithic self-Q-switched Cr,Nd:YAG laser where the chromium ions act as a saturable absorber for the laser emission at 1064 nm [1]. The pulse duration is 3.5 ns and the output is highly polarized with an extinction ratio of 700:1 [1]. It is further shown that the output is single-longitudinal-mode with transform-limited spectral line width without pulse-to-pulse mode competition [2]. Consequently, the pulse-to-pulse intensity fluctuation is less than the instrument resolution of 0.25% [2]. This self-stabilization mechanism is because the lasing mode bleaches the distributed absorber and establishes a gain-loss grating [3,4] similar to that used in the distributed feedback semiconductor lasers. Repetition rate above 5 KHz has also been demonstrated [3]. Figure 1 shows how compact, simple, and rugged this laser oscillator is. For higher power, this laser can be used for injection seeding an amplifier (or amplifier chain) or injection locking of a power oscillator pumped by diode lasers. We will discuss some research directions on the master oscillator for higher output energy per pulse as well as how to scale the output power of the diode-pumped amplifier (s) to multikilowatt average power.

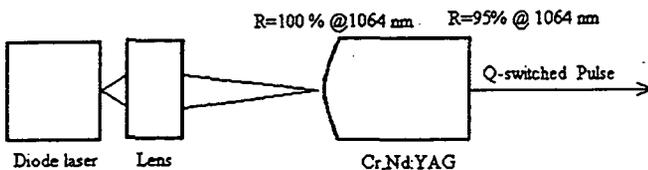


Fig. 1.

**References:** [1] Li S.-Q. et al. (1993) *Opt. Lett.*, 18, 203. [2] Li S.-Q. et al. (1993) *Opt. Lett.*, 18, April 1 issue. [3] Chen Y. C. et al. (1993) *Opt. Lett.*, 18, in press. [4] Li S.-Q., *Appl. Phys. Lett.*, submitted.

N93-28773160719

**PLANETARY AND SATELLITE X-RAY SPECTROSCOPY: A NEW WINDOW ON SOLID-BODY COMPOSITION BY REMOTE SENSING.** D. L. Chenette<sup>1</sup>, R. W. Wolcott<sup>1</sup>, and R. S. Selesnick<sup>2</sup>, <sup>1</sup>Lockheed R&D Division, Palo Alto CA 94304, USA, <sup>2</sup>Downs Laboratory, California Institute of Technology, Pasadena CA 91125, USA.

The rings and most of the satellites of the outer planets orbit within the radiation belts of their parent bodies, an environment with intense fluxes of energetic electrons. As a result these objects are strong emitters of X-rays. The characteristic X-ray lines from these bodies depend on atomic composition, but they are not sensitive to how the material is arranged in compounds or mixtures. X-ray fluorescence spectral analysis has demonstrated its unique value in the laboratory as a qualitative and quantitative analysis tool. This technique has yet to be fully exploited in a planetary instrument for remote sensing. The characteristic X-ray emissions provide atomic relative abundances. These results are complementary to the molecular composition information obtained from IR, visible, and UV emission spectra. The atomic relative abundances are crucial to understanding the formation and evolution of these bodies. They are also crucial to the proper interpretation of the molecular composition results from the other sensors. The intensities of the characteristic X-ray emissions are sufficiently strong to be measured with an instrument of modest size. Recent developments in X-ray detector technologies and electronic miniaturization have made possible space-flight X-ray imaging and nonimaging spectrometers of high sensitivity and excellent energy resolution that are rugged enough to survive long-duration space missions. Depending on the application, such instruments are capable of resolving elemental abundances of elements from carbon through iron. At the same time, by measuring the bremsstrahlung intensity and energy spectrum, the characteristics of the source electron flux can be determined. We will discuss these concepts, including estimated source strengths, and will describe a small instrument capable of providing this unique channel of information for future planetary missions. We propose to build this instrument using innovative electronics packaging methods to minimize size and weight.

5N93-28774160720

**POLARIMETRIC MULTISPECTRAL IMAGING TECHNOLOGY.** L.-J. Cheng, T.-H. Chao, M. Dowdy, C. Mahoney, and G. Reyes, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

The Jet Propulsion Laboratory is developing a remote sensing technology on which a new generation of compact, lightweight, high-resolution, low-power, reliable, versatile, programmable scientific polarimetric multispectral imaging instruments can be built to meet the challenge of future planetary exploration missions.

The instrument is based on the fast programmable acousto-optic tunable filter (AOTF) of tellurium dioxide (TeO<sub>2</sub>) that operates in

the wavelength range of 0.4–5  $\mu\text{m}$ . Basically, the AOTF multispectral imaging instrument measures incoming light intensity as a function of spatial coordinates, wavelength, and polarization. Its operation can be in either sequential, random access, or multiwavelength mode as required. This provides observational flexibility, allowing real-time alternation among desired observations, collecting needed data only, minimizing data transmission, and permitting implementation of new experiments. These will result in optimization of the mission performance with minimal resources.

This instrument can be used for two types of applications for future planetary exploration missions. First, the instrument is placed on a flight platform for mapping the interesting features on the surface and in the atmosphere of a planet or a moon. For example, this instrument is an excellent candidate as a visible-infrared imaging spectrometer for the Lunar Observer and a polarimetric imaging spectrometer for the Pluto Fast Flyby. The same instrument can be used to investigate atmospheric physics and chemistry of Jupiter and Saturn. In the other application, the instrument is used on a rover or a surface package on Mars and the Moon as an intelligent vision instrument for searching, identifying, mapping, and monitoring geological features, characterizing atmospheric contents and their time variability, as well as collecting valuable samples. For example, these instrument applications will support major scientific objectives of the Mars Environmental Survey (MESUR) program and the Evolutionary Mars Sample Return Program.

In the past we built two AOTF imaging spectrometer breadboard systems covering visible to short-wavelength infrared ranges and successfully demonstrated capabilities for identifying minerals and mapping content distributions, characterizing botanical objects, and measuring polarization signatures. In addition, we demonstrated the use of an optical fiber bundle as an image transfer vehicle in the AOTF system with the objective of developing an AOTF system with a flexible observation head for rover applications.

Recently we completed a polarimetric multispectral imaging prototype instrument and performed outdoor field experiments for evaluating application potentials of the technology. We also investigated potential improvements on AOTF performance to strengthen technology readiness for applications. This paper will give a status

report on the technology and a prospect toward future planetary exploration.

№ 93-28775 160721 p. 2

## A REMOTE LASER-MASS SPECTROMETER FOR DETERMINATION OF ELEMENTAL COMPOSITION.

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Determination of the elemental composition of lunar, asteroid, and planetary surfaces is a major concern for science and resource utilization of space. The science associated with the development of a satellite or lunar rover laser-mass spectrometer instrument is presented here. The instrument would include a pulsed laser with sufficient energy to create a plasma on a remote surface. Ions ejected from this plasma travel back to the spacecraft or rover, where they are analyzed by a time-of-flight mass spectrometer, giving the elemental and isotope composition. This concept is based on the LIMA-D instrument onboard the former Soviet Union Phobos-88 spacecraft sent to Mars.

A laser-mass spectrometer placed on a rover or satellite would substantially improve the data return over alternative techniques. The spatial resolution would be centimeters, and a complete mass spectrum could be achieved in one laser shot. An experiment is described (Fig. 1) that demonstrates these features.

A 400 mJ Nd:YAG laser is focused, to an intensity of  $10^{11}$  w/cm<sup>2</sup>, onto a Al, Ag, Cu, Ge, or lunar simulant target. A plasma forms from which ions are ejected. Some of these ions travel down an 18-m evacuated flight tube to a microchannel plate detector. Alternatively, the ions are captured by an ion trap where they are stored until pulsed into a 1-m time-of-flight mass spectrometer, giving the elemental composition of the remote surface. A television camera monitors the plasma plume shape, and a photo diode monitors the temporal plasma emission. With this system, ions of Al, Ag, Cu, Ge, and lunar simulant have been detected at 18 m. The mass spectrum from the ion trap and 1-m time-of-flight tube will be presented. Figure 2 shows ions of Al (1803 ev), Cu (1483 ev), Ag (1524 ev),

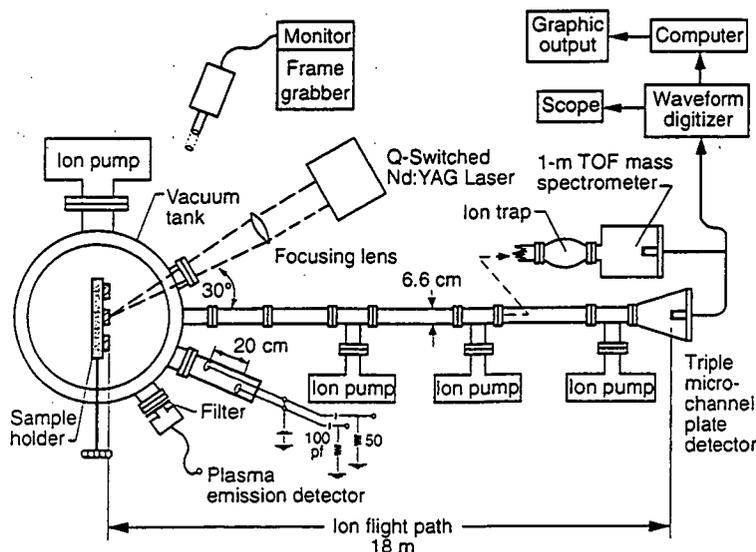


Fig. 1.

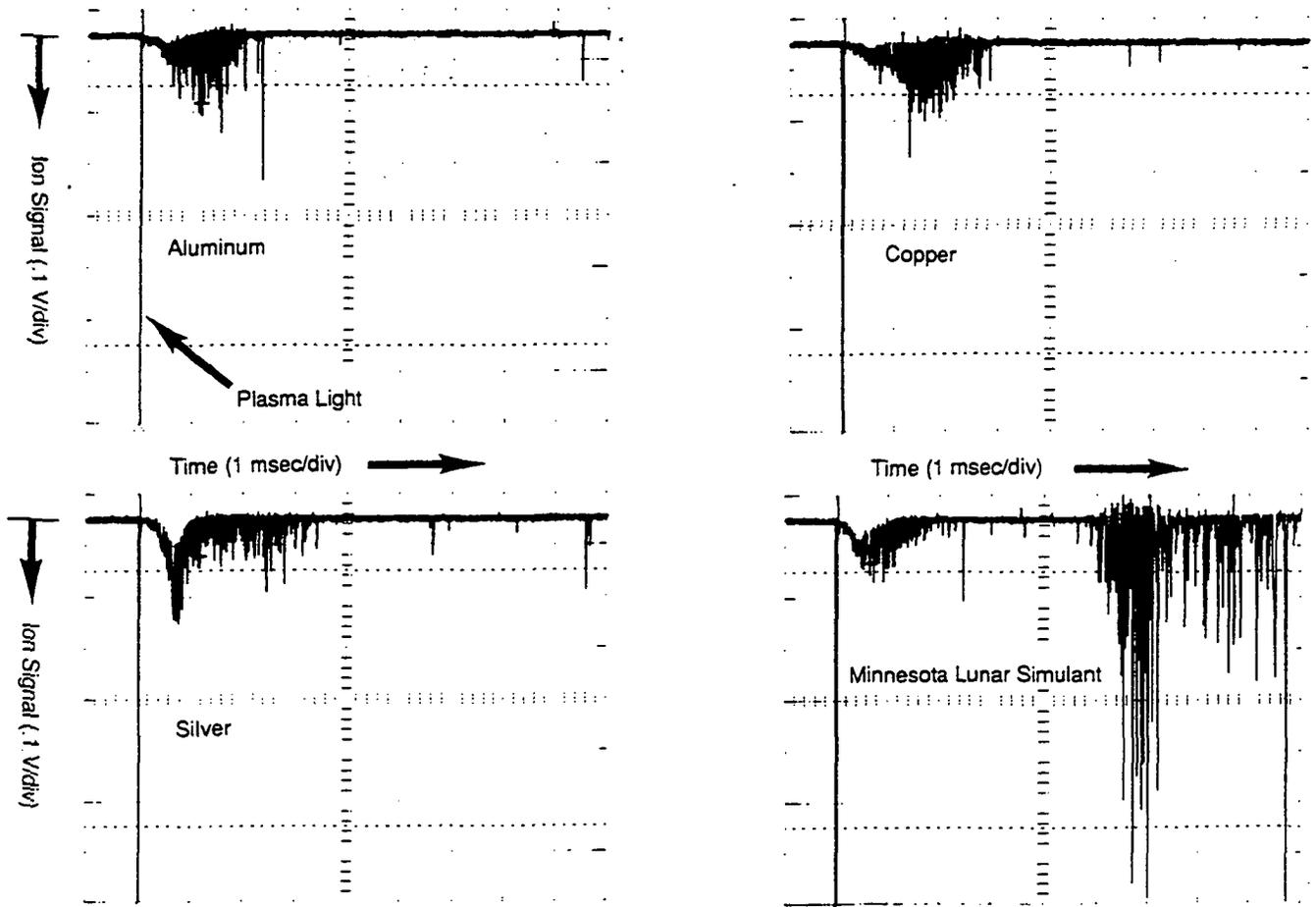


Fig. 2.

and lunar simulant detected at 18 m (bulk chemistry and mineralogy similar to Apollo 11 lunar mare basalts).

Experimental results will be presented that demonstrate the characteristics and ability of detecting laser-produced ions over very long distances.

fied uniquely in blind test analyses. Such identification is more accurate than can be obtained from any other remote spectroscopic technique.

The APX technique is based on three modes of nuclear and atomic interactions of alpha particles with matter resulting in three different energy spectra containing the compositional information. The instrument uses 50 to 100 mCi of  $^{242}\text{Cm}$  or  $^{244}\text{Cm}$  transuranium radioisotopes to provide a monoenergetic beam of alpha particles (6.01 MeV and 5.80 MeV respectively) and solid-state detectors for acquiring the energy spectra.

The technique has been used for the first time on the Surveyor missions in 1967-1968 to obtain the first chemical composition of the Moon. Since then the instrument has been miniaturized and refined to improve its performance. The alpha and proton detectors were combined into a single telescope with a very thin Si front detector that acts like an alpha detector and at the same time as an absorber of alpha particles for the proton detector in the back. An X-ray mode was incorporated into the instrument that is by itself equivalent to an X-ray fluorescence instrument. A rather complicated logic determines if the particle is an alpha, proton, or an

5/2 N93-28776/60722 P-2

**THE APX SPECTROMETER FOR MARTIAN MISSIONS.** T. Economou, Laboratory for Astrophysics and Space Research, University of Chicago, Chicago IL 60637, USA.

Obtaining the chemical composition of any planetary body should be a prime science objective of each planetary mission. The APX spectrometer has been designed to provide a detailed and complete chemical composition of all major (except H) and minor elements with high accuracy, *in situ* and remotely. From such complete analyses a first-order mineralogy of analyzed samples can be deduced. Laboratory studies in the past have shown that rock types (e.g., dunites, basalts, Philippinate 300 sample) were identi-

unwanted background event. This arrangement has improved the energy resolution of proton lines, eliminated the need for an additional guard detector system, and substantially reduced the size of the sensor head.

However, the big saving in size and power in the APX instrument comes from replacing the cryogenically cooled Si or HP Ge X-ray detectors in the X-ray mode with  $HgI_2$  ambient-temperature X-ray detectors that do not require cryogenic cooling to operate and still achieve high-energy resolution. These detectors are being provided by Xsirius, Inc. in Marina del Rey.

The spectrometer as it is implemented for Mars '94 and Mars '96 Russian missions (the Mars '94 and Mars '96 APX experiment are a collaboration of IKI of Moscow, The University of Chicago, and Max Planck Institut für Chemie in Mainz) and for NASA's Pathfinder mission (the APX experiment for Pathfinder will be a collaboration of MPI Mainz and The University of Chicago) to Mars in 1996 has a combined weight of about 600 g and operates on 250 mW of power. It still can benefit from higher-quality alpha sources available from the Russians and more hybridized electronics.

93-28747 7/60723 P-1

**INVESTIGATION OF MARS ROTATIONAL DYNAMICS USING EARTH-BASED RADIO TRACKING OF MARS LANDERS.** C. D. Edwards Jr., W. M. Folkner, R. D. Kahn, and R. A. Preston, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

The development of space geodetic techniques over the past two decades has made it possible to measure the rotational dynamics of the Earth at the milliarsecond level, improving our geophysical models of the Earth's interior and the interactions between the solid Earth and its atmosphere. We have found that the rotational dynamics of Mars can be determined to nearly the same level of accuracy by acquiring Earth-based two-way radio tracking observations of three or more landers globally distributed on the surface of Mars (Fig. 1). Our results indicate that the precession and long-term obliquity changes of the Mars pole direction can be determined to

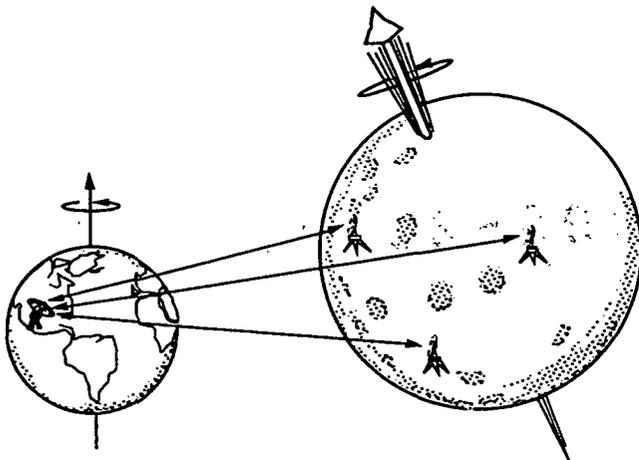


Fig. 1. Simultaneous two-way tracking of multiple Mars landers from Earth.

an angular accuracy corresponding to about 15 cm/yr at the planet's surface. In addition, periodic nutations of the pole and seasonal variations in the spin rate of the planet can be determined to 10 cm or less. Measuring the rotation of Mars at this accuracy would greatly improve the determination of the planet's moment of inertia and would resolve the size of a planetary fluid core, providing a valuable constraint on Mars interior models. Detecting seasonal variations in the spin rate of Mars would provide global constraints on atmospheric angular momentum changes due to sublimation of the Mars  $CO_2$  polar ice caps. Finally, observation of quasisecondular changes in Mars obliquity would have significant implications for understanding long-term climatic change.

The key to achieving these accuracies is a globally distributed network of Mars landers with stable, phase-coherent radio transponders. By simultaneously acquiring coherent two-way carrier phase observations between a single Earth tracking station and multiple Mars landers, Earth media errors are essentially eliminated, providing an extremely sensitive measure of changes in the differential path lengths between the Earth tracking station and the Mars landers due to Mars rotation. Time variability of the instrumental phase delay through the radio transponder may represent the limiting error source for this technique. Calibration of the transponder stability to about 0.1 ns or less; over a single tracking arc of up to 12 hr, is sufficient to provide the decimeter-level determination of Mars orientation parameters quoted above.

We will provide a detailed description of the multilander tracking technique and the requirements it imposes on both the lander radio system and the Earth-based ground-tracking system. This concept is currently part of the strawman science plan for the Mars Environmental Survey (MESUR) mission and complements many of the other MESUR science goals.

93-28747 8 160724 P-2

**CLEMENTINE SENSOR PROCESSING SYSTEM.** A. A. Feldstein, Innovative Concepts, Inc., 8200 Greensboro Drive, Suite 801, McLean VA 22102, USA.

The design of the DSPSE Satellite Controller (DSC) is baselined as a single-string satellite controller (no redundancy). The DSC performs two main functions: health and maintenance of the spacecraft, and image capture, storage, and playback. The DSC contains two processors, a radiation-hardened Mil-Std-1750, and a commercial R3000. The Mil-Std-1750 processor performs all housekeeping operations, while the R3000 is mainly used to perform the image processing functions associated with the navigation functions, as well as performing various experiments. The DSC also contains a data handling unit (DHU) used to interface to various spacecraft imaging sensors and to capture, compress, and store selected images onto the solid-state data recorder.

The development of the DSC evolved from several key requirements: The DSPSE satellite was to (1) have a radiation-hardened spacecraft control and be immune to single-event upsets (SEUs); (2) use an R3000-based processor to run the star tracker software that was developed by SDIO (due to schedule and cost constraints, there was no time to port the software to a radiation-hardened processor); and (3) fly a commercial processor to verify its suitability for use in a space environment.

In order to enhance the DSC reliability, the system was designed

with multiple processing paths. These multiple processing paths provide for greater tolerance to various component failures. The DSC was designed so that all housekeeping processing functions are performed by either the Mil-Std-1750 processor or the R3000 processor. The image capture and storage is performed either by the DHU or the R3000 processor.

The DSC interfaces to six sensors using two data and control buses. The image data are compressed using a JPEG compression device. The DHU is configured on a frame-by-frame basis to either store data in an uncompressed form or store data in a compressed form using one of the four compression tables stored in the JPEG device. The captured images are stored in a 1.6-Gbit solid-state recorder that is part of the DSC for playback to the ground. Images can be captured by the DSC either on demand, one frame at a time, or by preloading a sequence of images to be captured by the DHU without processor or ground intervention.

As for the future, the Naval Research Laboratory is currently developing a fault-tolerant spacecraft controller using the RH3000 processor chip set. The processor includes shadow checker, real time hardware rollback, fault-tolerant memory, hardware cache coherence, and more.

S15 N93-2877960725 p.1

**DESIGN CONCEPT FOR AN IR MAPPING SPECTROMETER FOR THE PLUTO FAST FLYBY MISSION.** U. Fink<sup>1</sup>, F. Low, B. Hubbard, M. Rieke, G. Rieke, M. Mumma, S. Nozette, G. Neukum, H. Hamel, M. DiSanti, M. Buie, and A. Hoffman, <sup>1</sup>Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, USA.

The design of an IR mapping spectrometer that exceeds all the criteria of the Pluto Fast Flyby Mission will be presented. The instrument has a mass of ~1700 g and uses less than 4 W of power. The design concept is based on an  $f/3$  spectrograph using an aberration-corrected concave holographic grating. Up to four spectral regions can be covered simultaneously by dividing the grating into two to four sections, each imaging the entrance slit on a different area of the array. The spectrography will be fed by a lightweight 5"  $f/3$  telescope based on SDIO precepts. In order to provide spectroscopic access to the fundamental molecule frequencies, an extended-range NICMOS array to ~3.5  $\mu\text{m}$  and an InSb array going to 5.8  $\mu\text{m}$  will be considered.

S16 N93-28780160726 p.1

**MULTIBEAM LASER ALTIMETER FOR PLANETARY TOPOGRAPHIC MAPPING.** J. B. Garvin, J. L. Bufton, and D. J. Harding, Laboratory for Terrestrial Physics, Code 920, Goddard Space Flight Center, Greenbelt MD 20771, USA.

Laser altimetry provides an active, high-resolution, high-accuracy method for measurement of planetary and asteroid surface topography. The basis of the measurement is the timing of the round-trip propagation of short-duration pulses of laser radiation between a spacecraft and the surface. Vertical, or elevation, resolution of the altimetry measurement is determined primarily by laser pulsewidth, surface-induced spreading in time of the reflected pulse, and the timing precision of the altimeter electronics. With

conventional gain-switched pulses from solid-state lasers and nanosecond resolution timing electronics, submeter vertical range resolution is possible anywhere from orbital altitudes of ~1 km to altitudes of several hundred kilometers. Horizontal resolution is a function of laser beam footprint size at the surface and the spacing between successive laser pulses. Laser divergence angle and altimeter platform height above the surface determine the laser footprint size at the surface; while laser pulse repetition rate, laser transmitter beam configuration, and altimeter platform velocity determine the spacing between successive laser pulses.

Multiple laser transmitters in a single laser altimeter instrument that is orbiting above a planetary or asteroid surface could provide across-track as well as along-track coverage that can be used to construct a range image (i.e., topographic map) of the surface. We are developing a pushbroom laser altimeter instrument concept that utilizes a linear array of laser transmitters to provide contiguous across-track and along-track data. The laser technology is based on the emerging monolithic combination of individual, 1-cm<sup>2</sup> diode-pumped Nd:YAG laser pulse emitters. The laser pulse output at 1  $\mu\text{m}$  that results from each element is approximately 1 ns in duration and is powerful enough to measure distance to the surface from short range (1–10 km). Laser pulse reception is accomplished in this concept by a single telescope that is staring at nadir and is equipped with a single detector element in its focal plane. This arrangement permits a fixed alignment of each transmitter output into a separate, dedicated sensor footprint, yet minimizes instrument complexity. For example, a linear array of 20 laser transmitters oriented perpendicular to the orbit motion could map an asteroid surface at a spatial resolution of 50 m in a 1-km swath. The two-dimensional topographic image might be most appropriate for missions in which multispectral imaging data are also acquired. The instrument is also capable of laser pulse energy measurement for each sensor footprint, yielding a measure of surface reflectance at the monochromatic 1- $\mu\text{m}$  laser wavelength.

It should also be possible to produce a device that is capable of simultaneous operation on all elements for long-range operation at the millijoule-per-pulse performance level or time-division-multiplexed operation of single laser emitter elements to produce the desired pushbroom laser altimeter sensor pattern on the planetary or asteroid surface. Thus the same device could support operational ranging to an asteroid from long range and scientific observations at high resolution simply by simultaneously or sequentially addressing the multiple laser transmitter elements. Details of the multi-emitter laser transmitter technology, the instrument configuration, and performance calculations for a realistic Discovery-class mission will be presented.

S17 N93-28781160727 p.2

**ACOUSTO-OPTIC INFRARED SPECTRAL IMAGER FOR PLUTO FAST FLYBY.** D. A. Glenar<sup>1</sup> and J. J. Hillman<sup>2</sup>, <sup>1</sup>Photonics Branch, Code 715, NASA Goddard Space Flight Center, Greenbelt MD 20771, USA, <sup>2</sup>Laboratory for Extraterrestrial Physics, Code 690, NASA Goddard Space Flight Center, Greenbelt MD 20771, USA.

Acousto-optic tunable filters (AOTFs) enable compact, two-dimensional imaging spectrometers with high spectral and spatial resolution and with no moving parts. Tellurium dioxide AOTFs operate from about 400 nm to nearly 5  $\mu\text{m}$ , and a single device will

tune continuously over one octave by changing the RF acoustic frequency applied to the device.

An infrared (1.2–2.5  $\mu\text{m}$ ) Acousto-Optic Imaging Spectrometer (AIMS) has been designed that closely conforms to the surface composition mapping objectives of the Pluto Fast Flyby. It features a 75-cm focal length telescope, infrared AOTF, and  $256 \times 256$  NICMOS-3 focal plane array for acquiring narrowband images with a spectral resolving power ( $\lambda/\Delta\lambda$ ) exceeding 250.

We summarize the instrument design features and its expected performance at the Pluto-Charon encounter.

SN-93-287820728 P-1

**THERMAL ANALYZER FOR PLANETARY SOILS (TAPS): AN *IN SITU* INSTRUMENT FOR MINERAL AND VOLATILE-ELEMENT MEASUREMENTS.** J. L. Gooding<sup>1</sup>, D. W. Ming<sup>1</sup>, J. E. Gruener<sup>2</sup>, F. L. Gibbons<sup>2</sup>, and J. H. Allton<sup>2</sup>. <sup>1</sup>Code SN, NASA Johnson Space Center, Houston TX 77058, USA, Code C23, Lockheed Engineering and Sciences Co., Houston TX 77058, USA.

TAPS offers a specific implementation for the generic thermal analyzer/evolved-gas analyzer (TA/EGA) function included in the Mars Environmental Survey (MESUR) strawman payload; applications to asteroids and comets are also possible [1]. The baseline TAPS is a single-sample differential scanning calorimeter (DSC), backed by a capacitive-polymer humidity sensor, with an integrated sampling mechanism [2]. After placement on a planetary surface, TAPS acquires 10–50 mg of soil or sediment and heats the sample from ambient temperature to 1000–1300 K (Fig. 1). During heating, DSC data are taken for the solid and evolved gases are swept past the water sensor. Through groundbased data analysis, multicomponent DSC data are deconvolved [3] and correlated with the water-release profile to quantitatively determine the types and relative proportions of volatile-bearing minerals such as clays and other hydrates, carbonates, and nitrates (Fig. 2). The rapid-response humidity sensors also achieve quantitative analysis of total water [4]. After conclusion of soil-analysis operations, the humidity sensors become available for meteorology.

The baseline design fits within a circular-cylindrical volume

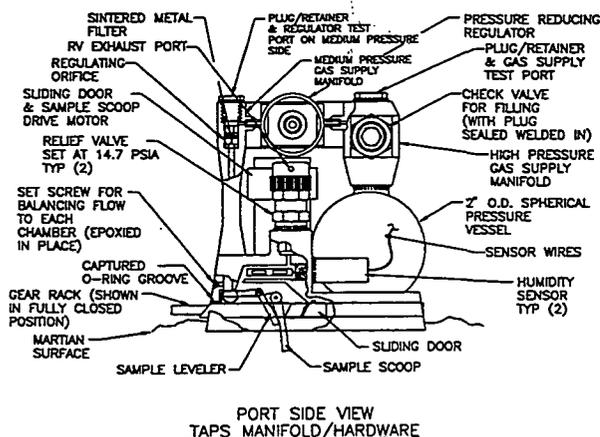


Fig. 1. TAPS Mark-1B packaging concept.

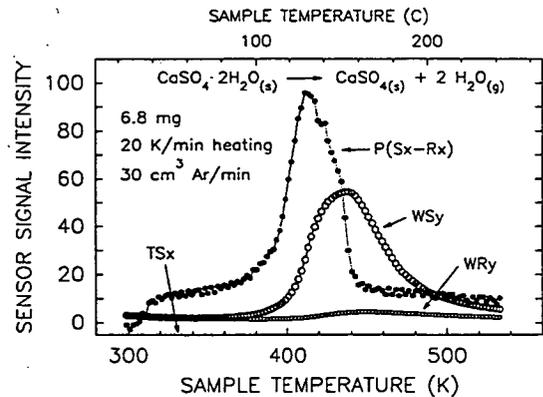


Fig. 2. Simultaneous DSC [P(Sx-Rx) spline] and evolved-water [WSy spline] data from analysis of gypsum by the TAPS Mark-1 sensor testbed.

<1000  $\text{cm}^3$ , occupies 1.2 kg mass, and consumes about 2 Whr of power per analysis. Enhanced designs would acquire and analyze multiple samples and employ additional microchemical sensors for analysis of  $\text{CO}_2$ ,  $\text{SO}_2$ ,  $\text{NO}_x$ , and other gaseous species. Atmospheric pumps are also being considered as alternatives to pressurized purge gas.

**References:** [1] Gooding J. L. (1989) in *Proc. 18th North Amer. Thermal Anal. Soc. Conf.*, Vol. 1 (I. R. Harrison, ed.), 222–228. [2] Gooding J. L. (1991) *LPSCXXII*, 457–458. [3] Gooding J. L. (1991) in *Proc. 20th North Amer. Thermal Anal. Soc. Conf.* (M. Y. Keating, ed.), 329–334. [4] Gooding J. L. et al. (1992) in *Proc. 21st North Amer. Thermal Anal. Soc. Conf.* (W. Sichina, ed.), 477–481.

SN-93-28783 160729 P-2

**IMAGING SPECTROMETERS USING CONCAVE HOLOGRAPHIC GRATINGS.** J. Gradie<sup>1</sup> and S. Wang<sup>2</sup>, <sup>1</sup>Terra Systems, Inc., 169 Kuukama Street, Kailua HI, 96734, USA, <sup>2</sup>SETS Technology, Inc., 300 Kahelu Avenue, Mililani HI 96789, USA.

Imaging spectroscopy combines the spatial attributes of imaging with the compositionally diagnostic attributes of spectroscopy. Imaging spectroscopy is useful wherever the spatial variation of spectral properties is important, such as mapping spectrally distinct compositional units on surfaces (planetary, terrestrial, medical, industrial), spectral emission and absorption of gases and surfaces (planetary, etc.), or regional spectral changes over time.

Imaging spectrometers produce a series of spatial images at many wavelengths in a number of ways: (1) a single-spot field of view that is step-wise scanned over the spatial field while the wavelengths (or wavenumbers) are scanned sequentially (single-detector element), (2) a single-spot field of view that continuously scans the field of view while sampling all wavelengths simultaneously (a linear-array detector), (3) a slit that continuously scans the field of view while sampling all wavelengths simultaneously (a two-dimensional array detector), or (4) frames of the full field of view taken at sequential wavelengths.

For spacebased remote sensing applications, mass, size, power, data rate, and application constrain the scanning approach. For the first three approaches, substantial savings in mass and size of the

spectrometer can be achieved in some cases with a concave holographic grating and careful placement of an order-sorting filter. A hologram etched on the single concave surface contains the equivalent of the collimating, dispersing, and camera optics of a conventional grating spectrometer and provides substantial wavelength-dependent corrections for spherical aberrations and a flat focal field. These gratings can be blazed to improve efficiency when used over a small wavelength range or left unblazed for broadband uniform efficiency when used over a wavelength range of up to 2 orders. More than 1 order can be imaged along the dispersion axis by placing an appropriately designed step order-sorting filter in front of the one- or two-dimensional detector. This filter can be shaped for additional aberration corrections. The VIRIS™ imaging spectrometer based on the broadband design provides simultaneous imaging of the entrance slit from  $\lambda = 0.9$  to  $2.6 \mu\text{m}$  (1.5 orders) onto a  $128 \times 128$  HgCdTe detector (at 77 K). The VIRIS™ spectrometer has been used for lunar mapping with the UH 24-in telescope at Mauna Kea Observatory. The design is adaptable for small, low-mass, spacebased imaging spectrometers.

#### THE ULTRAVIOLET PLUME INSTRUMENT (UVPI).

D. M. Horan, Naval Center for Space Technology, Naval Research Laboratory, Washington DC 20375-5354, USA.

The Ultraviolet Plume Instrument (UVPI) was launched aboard the Low-power Atmospheric Compensation Experiment (LACE) satellite on February 14, 1990. Both the spacecraft and the UVPI were sponsored by the Directed Energy Office of the Strategic Defense Initiative Organization. The mission of the UVPI was to obtain radiometrically calibrated images of rocket plumes at high altitude and background image data of the Earth, Earth's limb, and celestial objects in the near- and middle-UV wavebands. The UVPI was designed for nighttime observations, i.e., to acquire and track relatively bright objects against a dark background.

Two coaligned, intensified charge-coupled device cameras were used to locate the object of interest, control UVPI, and obtain images and radiometric data. The tracker camera and the plume camera shared a fixed 10-cm-diameter Cassegrain telescope that used a gimbaled plane steering mirror to view a field of regard that was a  $50^\circ$  half-angle cone about the spacecraft's nadir. Additionally, a plane mirror on the instrument's door could be used with the steering mirror to extend the field of regard to view the Earth's limb and stars near the limb in a southerly direction.

The tracker camera had a relatively wide field of view,  $2.0^\circ$  by  $2.6^\circ$ , and a single bandpass of 255–450 nm. The tracker camera had three functions. First, its wide field of view and bright image were used to find the object of interest. Second, images from the tracker camera could be processed within UVPI and the results used to control the gimbaled mirror for autonomous tracking of the target. Third, the tracker camera was calibrated and could obtain radiometric data within its bandpass.

The plume camera had a much narrower field of view,  $0.18^\circ$  by  $0.14^\circ$ , and had a correspondingly higher resolution than the tracker camera. The plume camera had a four-position filter wheel to provide four bandpasses: 195–295 nm, 220–320 nm, 235–350 nm, and 300–320 nm. Only one bandpass could be selected at a time. The purpose of the plume camera was to obtain high-resolution images and radiometric data within its bandpasses.

The UVPI collected high-quality, calibrated UV emission im-

ages from four rocket launches in four attempts. These successful observations have provided more than 150 s of calibrated plume images from space. The plume camera data obtained for these high-altitude plumes in the 195–295 nm and 220–320 nm bandpasses is not obtainable from the ground because it is blocked by the Earth's ozone layer. All UVPI plume observation data have been processed by the NRL LACE Program and archived in the SDIO Plumes Data Center at Arnold AFB, Tennessee, and the SDIO Backgrounds Data Center at NRL.

Background observations include southern auroral events, measurements of the Earth's limb under different lighting conditions, nadir scans, measurements near an erupting volcano, and measurements of emission from city and highway lighting. Data from all UVPI observations has been processed and deposited in the SDIO Backgrounds Data Center at NRL.

Radiometric calibration of the UVPI was done before launch and confirmed after launch by star observations. Stars of known emission spectrum based on measurements by other spaceborne sensors were used. The calibration values obtained using the stars are close to the calibration values obtained before launch.

#### OMIT

THE ATMOSPHERIC ULTRAVIOLET RADIANCE INTEGRATED CODE (AURIC): VALIDATION OF VERSION 1.0. R. E. Huffman<sup>1</sup>, J. Zdyb<sup>1</sup>, R. Link<sup>2</sup>, and D. J. Strickland<sup>2</sup>, <sup>1</sup>Phillips Laboratory/Geophysics Directorate, Hanscom AFB MA 01731, USA, <sup>2</sup>Computational Physics, Inc., Fairfax VA 22031, USA.

This abstract was withdrawn by the author.

MICROTEXTURED METALS FOR STRAY-LIGHT SUPPRESSION IN THE CLEMENTINE STAR-TRACKER. E. A. Johnson, Spire Corporation, One Patriots Park, Bedford MA 01730, USA.

Anodized blacks for suppressing stray light in optical systems can now be replaced by microscopically textured metal surfaces.

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This presentation will detail an application of these black surfaces to the Clementine star-tracker navigational system, which will be launched in early 1994 to examine the Moon, en route to intercept an asteroid. Rugged black surfaces with Lambertian BRDF  $<10^{-2}$   $\text{srad}^{-1}$  are critical for suppressing stray light in the star-tracker optical train. Previously available materials spall under launch vibrations to contaminate mirrors and lenses. Microtextured aluminum is nearly as dark, but much less fragile. It is made by differential ion beam sputtering, which generates light-trapping pores and cones slightly smaller than the wavelength to be absorbed. This leaves a sturdy but light-absorbing surface that can survive challenging conditions without generating debris or contaminants. Both seeded ion beams and plasma immersion (from ECR plasmas) extraction can produce these microscopic textures without fragile interfaces. Process parameters control feature size, spacing, and optical effects (THR, BRDF). Both broad and narrow absorption bands can be engineered with tuning for specific wavelengths and applications. Examples will be presented characterized by FTIR in reflection mode. Textured metal blacks are also ideal for blackbody calibrators (0.95 normal emissivity), heat rejection, and enhanced nucleate boiling.

R.1 N93-28785 160732  
**NEW TECHNOLOGIES FOR UV DETECTORS.** C. L. Joseph, Space Astronomy Laboratory, University of Wisconsin, 1150 University Avenue, Madison WI 53706, USA.

Several technologies are currently being developed, leading to substantial improvements in the performance of UV detectors or significant reductions in power or weight. Four technologies discussed are (1) thin-film coatings to enhance the UV sensitivity of CCDs, (2) highly innovative magnet assemblies that dramatically reduce weight and result in virtually no external flux, (3) new techniques for curving microchannel plates (MCPs) so that single plates can be used to prevent ion feedback and present highly localized charge clouds to an anode structure, and (4) high-performance alternatives to glass-based MCPs. In item (2), for example, very robust magnets are made out of rare earth materials such as samarium cobalt, and cladding magnets are employed to prevent flux from escaping from the detector into the external environment. These new ultralight magnet assemblies are able to create strong, exceptionally uniform magnetic fields for image intensification and focusing of photoelectrons. The principle advantage of such detectors is the quantum efficiencies of 70–80% obtained throughout ultraviolet wavelengths (900–2000 Å), the highest of any device.

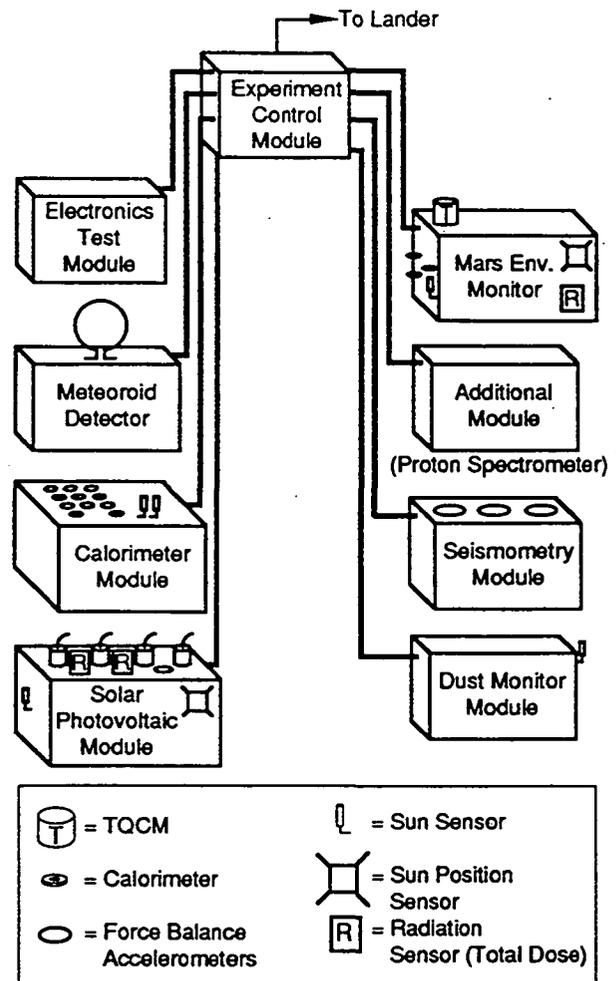
Despite the improvements achieved under item (3), high-performance alternatives to conventional glass-based MCPs potentially offer three distinct new advantages that include (1) a 30–100-fold improvement in dynamic range resulting in correspondingly higher signal-to-noise ratios, (2) the use of pure dielectric and semiconductor materials that will not outgas contaminants that eventually destroy photocathodes, and (3) channels that have constant spacing providing long-ranged order since the plates are made using photolithography techniques from the semiconductor industry. The manufacturers of these advanced-technology MCPs, however, are a couple of years away from actually producing a functioning image intensifier.

In contrast to the use of CCDs for optical, groundbased observations, there is no single detector technology in the ultraviolet that

dominates or is as universally suitable for all applications. Thus, we address several technological problems, recent advances, and the impact that these new enabling technologies represent for UV applications.

N93-28787 160733 p-2  
**LIGHTWEIGHT MODULAR INSTRUMENTATION FOR PLANETARY APPLICATIONS.** P. B. Joshi, Physical Sciences Inc., 20 New England Business Center, Andover MA 01810, USA.

Physical Sciences Inc. is currently developing under SDIO sponsorship an instrumentation suite for monitoring the spacecraft environment and for accurately measuring the degradation of space materials in LEO. The instrumentation, called SAMMES (Space Active Modular Materials ExperimentS), features compact (~6-in



- System control module not needed for autonomic instrument modules
- Sensors can be on module or remotely wired to module
- RS 422 Command/Data Interface between modules and lander/controller

Fig. 1. Sensor/instrumentation concept for lunar/martian application.

cube), lightweight (~2.5 kg) modules incorporating a variety of sensors and low-power (~5 W) processing electronics. The LEO Environment Monitor Module (EMM) sensor complement consists of two passively called Quartz Crystal Microbalances and three calorimeters for contaminant detection/characterization, three actinometers for measuring AO flux, two RADFETs for total dose radiation measurement, a Sun position sensor, and a solar irradiance sensor. The EMM is designed as a remote terminal for MIL-STD-1553B communication with an experiment bus controller and for independent operation of its sensors. The present design can be modified to be fully autonomous, with module-based mass memory, onboard data processing, and software upload capability.

The SAMMES architecture concept can be extended to instrumentation for planetary exploration, both on spacecraft and *in situ*. The operating environment for planetary application will be substantially different, with temperature extremes and harsh solar wind and cosmic ray flux on lunar surfaces and temperature extremes and high winds on venusian and martian surfaces. Moreover, instruments for surface deployment, which will be packaged in a small lander/rover (as in MESUR, for example), must be extremely compact with ultralow power and weight. With these requirements in mind, we have extended the SAMMES concept to a sensor/instrumentation scheme for the lunar and martian surface environment, as illustrated in Fig. 1.

**OPTICAL TECHNOLOGIES FOR UV REMOTE SENSING INSTRUMENTS.** R. A. M. Keski-Kuha, J. F. Osantowski, D. B. Leviton, T. T. Saha, D. A. Content, R. A. Boucarut, J. S. Gum, G. A. Wright, C. M. Fleetwood, and T. J. Madison, NASA Goddard Space Flight Center, Greenbelt MD 20771, USA.

Over the last decade significant advances in technology have made possible development of instruments with substantially improved efficiency in the UV spectral region. In the area of optical coatings and materials, we discuss the importance of recent developments in chemical vapor deposited (CVD) silicon carbide (SiC) mirrors, SiC films, and multilayer coatings in the context of ultraviolet instrumentation design. For example, the development of chemically vapor deposited (CVD) silicon carbide (SiC) mirrors, with high ultraviolet (UV) reflectance and low scatter surfaces, provides the opportunity to extend higher spectral/spatial resolution capability into the 50-nm region. Optical coatings for normal incidence diffraction gratings are particularly important for the evolution of efficient extreme ultraviolet (EUV) spectrographs. SiC films are important for optimizing the spectrograph performance in the 90-nm spectral region.

Diffraction grating technology has always played a pivotal role in the development of spectroscopic instrumentation for ultraviolet space flight instrumentation. An essential element in the successful diffraction grating development program is the ability to quantitatively evaluate the performance of test diffraction gratings in the early stages of the instrument development program. The Diffraction Grating Evaluation Facility (DGEF) at Goddard Space Flight Center was established to evaluate the performance of new technology diffraction gratings and other optical components for future spaceflight instrumentation especially in the vacuum ultraviolet. DGEF is a unique, world-class, extremely versatile facility with enormous evacuable optical set-up volume allowing mirrors and

gratings to be evaluated in their design configurations with respect to design specifications, manufacturer's data, and optical analytical results.

We will discuss the performance evaluation of the flight optical components for the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instrument, a spectroscopic instrument to fly aboard the Solar and Heliospheric Observatory (SOHO) mission, designed to study dynamic processes, temperatures, and densities in the plasma of the upper atmosphere of the Sun in the wavelength range from 50 nm to 160 nm. The optical components were evaluated for imaging and scatter in the UV. We will also review the performance evaluation of SOHO/CDS (Coronal Diagnostic Spectrometer) flight gratings tested for spectral resolution and scatter in the DGEF and present preliminary results on resolution and scatter testing of Space Telescope Imaging Spectrograph (STIS) technology development diffraction gratings.

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**MULTISCALE MORPHOLOGICAL FILTERING FOR ANALYSIS OF NOISY AND COMPLEX IMAGES.** A. Kher and S. Mitra, Computer Vision and Image Analysis Laboratory, Department of Electrical Engineering, Texas Tech University, Lubbock TX 79410, USA.

Images acquired with passive sensing techniques suffer from illumination variations and poor local contrasts that create major difficulties in interpretation and identification tasks. On the other hand, images acquired with active sensing techniques based on monochromatic illumination are degraded with speckle noise. Mathematical morphology offers elegant techniques to handle a wide range of image degradation problems. Unlike linear filters, morphological filters do not blur the edges and hence maintain higher image resolution. Their rich mathematical framework facilitates the design and analysis of these filters as well as their hardware implementation. Morphological filters are easier to implement and are more cost effective and efficient than several conventional linear filters. Morphological filters to remove speckle noise while maintaining high resolution and preserving thin image regions that are particularly vulnerable to speckle noise [1] have been developed and applied to SAR imagery. These filters used combination of linear (one-dimensional) structuring elements in different (typically four) orientations (the median operators by Maragos [2]). Although this approach preserves more details than the simple morphological filters using two-dimensional structuring elements, the limited orientations of one-dimensional elements approximate the fine details of the region boundaries. A more robust filter designed recently overcomes the limitation of the fixed orientations. This filter uses a combination of concave and convex structuring elements. Morphological operators are also useful in extracting features from visible and infrared imagery. A multiresolution image pyramid obtained with successive filtering and a subsampling process aids in the removal of the illumination variations and enhances local contrasts. A morphology-based interpolation scheme has also been introduced to reduce intensity discontinuities created in any morphological filtering task. The generality of morphological filtering techniques in extracting information from a wide variety of images obtained with active and passive sensing techniques will be discussed. Such techniques are particularly useful in obtaining more

524 ~~NO 34-28789~~ 160734 p. 1

information from fusion of complex images acquired by different sensors such as SAR, visible, and infrared [3].

**References:** [1] Kher A. and Mitra S. (1992) *Proc. SPIE*. [2] Maragos P. (1989) *IEEE Trans. Pattern Anal. Mach. Intellig.*, 11. [3] Mitra S. and Kher A. (1992) Paper presented at the International Space Year Conference at JPL, Pasadena, California, 10-13 February, 1992.

*P. 1*  
 93-28790 160736  
**A UNIQUE PHOTON BOMBARDMENT SYSTEM FOR SPACE APPLICATIONS.** E. J. Klein, KET Canada Inc./Sol-RF Energy Systems Inc., Box 2550, Winnipeg, Canada, R3C 4B3.

The innovative (patents pending) Electromagnetic Radiation Collection and Concentration System (EMRCCS) described here is the foundation for the development of a multiplicity of space and terrestrial system formats. The system capability allows its use in the visual, infrared, and ultraviolet ranges of the spectrum for EM collection, concentration, source/receptor tracking, and targeting.

The nonimaging modular optical system uses a physically static position aperture for EM radiation collection. Folded optics provide the concentration of the radiation and source autotracking. The collected and concentrated electromagnetic radiation is utilized in many applications, e.g., solar spectrum in thermal and associative photon bombardment applications for hazardous waste management, water purification, metal hardening, hydrogen generation, photovoltaics, etc., in both space and terrestrial segment utilization. Additionally, at the high end of the concentration capability range, i.e., 60,000+, a solar-pulsed laser system is possible.

The system outputs the concentrated flux, orthogonal (normally incident) to the input plane of an output port. The orthogonality remains constant regardless of the radiation input angle to the collection aperture, allowing simplification of radiation receptor design and highly efficient utilization of the concentrated radiation. The system configuration is arrayed for extremely high levels of flux concentration in windowing and targeting applications. Other system design formats provide power generation and thermal processes for heating and absorption cooling.

Fixed portable and mobile (space and terrestrial) applications include designs that incorporate a phased RF and/or the system array for purposes of radiation source acquisition/tracking and data derivation. The data is utilized in source acquisition (array capture angle of  $\pm 75^\circ$  in the orthogonal E and H planes), source autotracking in the same angular intervals, and, subsequent to source and receptor acquisition, control of direction and magnitude of the output concentrated radiation at a given target range. In addition, the phased array can provide EM channel voice or data capability.

*P. 1*  
 93-28791 160737  
**DETECTION OF OTHER PLANETARY SYSTEMS USING PHOTOMETRY.** D. Koch<sup>1</sup>, W. Borucki<sup>1</sup>, and H. Reitsem<sup>2</sup>, <sup>1</sup>Mail Stop 245-6, NASA Ames Research Center, Moffett Field CA 94035, USA, <sup>2</sup>Ball Aerospace Systems Group, P.O. Box 1062, Boulder CO 80306, USA.

Detection of extrasolar short-period planets, particularly if they are in the liquid-water zone, would be one of the most exciting discoveries of our lifetime. A well-planned space mission has the capability of making this discovery using the photometric method.

An Earth-sized planet transiting a Sun-like star will cause a decrease in the apparent luminosity of the star by one part in 10,000 with a duration of about 12 hours and a period of about one year. Given a random orientation of orbital plane alignments with the line-of-sight to a star, and assuming our solar system to be typical, one would expect 1% of the stars monitored to exhibit planetary transits. A null result would also be significant and indicate that Earth-sized planets are rare.

For the mission to be successful one needs a sensor system that can simultaneously monitor many thousands of stars (F, G, and K dwarfs) with a photometric precision of one part in 30,000 per hour of integration. The stellar magnitude, integration time, and desired photometric precision determine the aperture size. The field of view and limiting stellar magnitude determine the number of stars that can be monitored. A 1.5-m telescope is required to attain the photometric precision for 12.5 mag stars. An 8° field of view will yield many thousands of stars and several transit detections per month. Confirmation of a detection will involve detection of a second transit that will yield a period and predict the time for a third and subsequent transits.

The technology issues that need to be addressed are twofold: One is for an appropriate optical design; the other is for a detector system with the necessary photometric precision. Two candidates for the detector system are silicon diodes and CCDs. It has been demonstrated that discrete silicon diodes have the required precision. However, the technology for building them into arrays with readouts needs development. The other approach is to use silicon CCDs. These already exist as arrays. However, the required photometric precision technology has yet to be demonstrated. Data processing complexity can be reduced by using the local-area-readout technique to obtain the flux for a few hundred stars per CCD.

*P. 2*  
 93-28792 160738  
**AN INTEGRATED XRF/XRD INSTRUMENT FOR MARS EXOBIOLOGY AND GEOLOGY EXPERIMENTS.** L. N. Koppel<sup>1</sup>, E. D. Franco<sup>1</sup>, J. A. Kerner<sup>1</sup>, M. L. Fonda<sup>2</sup>, D. E. Schwartz<sup>2</sup>, and J. R. Marshall<sup>2</sup>, <sup>1</sup>ARACOR, 425 Lakeside Drive, Sunnyvale CA 94086-4701, USA, <sup>2</sup>Mail Stop 239-12, NASA Ames Research Center, Moffett Field CA 94035-1000, USA.

By employing an integrated X-ray instrument on a future Mars mission, data obtained will greatly augment those returned by Viking; details characterizing the past and present environment on Mars and those relevant to the possibility of the origin and evolution of life will be acquired. A combined XRF/XRD instrument has been breadboarded and demonstrated to accommodate important exobiology and geology experiment objectives outlined for MESUR and future Mars missions. Among others, primary objectives for the exploration of Mars include the intense study of local areas on Mars to "establish the chemical, mineralogical, and petrological character of different components of the surface material; to determine the distribution, abundance, and sources and sinks of volatile materials, including an assessment of the biologic potential, now and during past epoches; and to establish the global chemical and physical characteristics of the martian surface" [1].

The XRF/XRD breadboard instrument identifies and quantifies soil surface elemental, mineralogical, and petrological characteristics and acquires data necessary to address questions on volatile abundance and distribution. Additionally, the breadboard is able to

characterize the biogenic element constituents of soil samples providing information on the biologic potential of the Mars environment. For example, experimental results employing the breadboard indicate that accurate and precise data including the detection, identification, and quantification of elements to trace levels (ppm) from carbon to zirconium ( $6 < Z < 40$ ), as well as relative abundance of amorphous vs. crystalline minerals in Mars soil surface samples, can be obtained. The breadboard has been designed and built with regard to expected Mars environmental operating conditions, mission constraints, and technical requirements that include general instrument design considerations.

Preliminary XRF/XRD breadboard experiments have confirmed the fundamental instrument design approach and measurement performance. Experimental accomplishments and results include the following: XRD observation of the principal diffraction lines of montmorillonite; XRF measurement of aluminum, silicon, calcium, titanium, and iron abundances in palagonite powder samples commensurate with expectations; and calibration of a carbon-detecting XRF channel with detectability limits in the order of 0.01 wt%.

The breadboard experiments provided valuable confirmation of models used to simulate and optimize the instrument's performance and indicated practical improvements in its design.

**References:** [1] COMPLEX (1978) National Academy of Sciences, Washington, DC, 97 pp.

*S29-11* **N93-28793** / 60739  
ABS. ONLY

**REMOTE MEASUREMENT OF PLANETARY MAGNETIC FIELDS BY THE HANLE EFFECT.** C. K. Kumar<sup>1,2</sup>, L. Klein<sup>1,2</sup>, and M. Giraud<sup>3</sup>, <sup>1</sup>Department of Physics and Astronomy, Howard University, Washington DC 20059, USA, <sup>2</sup>Center for the Study of Terrestrial and Extra-Terrestrial Atmospheres, Howard University, Washington DC 20059, USA, <sup>3</sup>Departement de Physique, Université de Provence/St. Jerome, Marseilles, France.

Resonance fluorescence lines in the spectra of planetary atmospheres are polarized. They will be depolarized by magnetic fields in the scattering medium (Hanle effect). The amount of depolarization has been calculated for some atomic (FeI, CaI) lines and some molecular lines (NO  $\gamma$  bands) seen in the Earth's dayglow spectra. The results are presented and the potential advantages of LIDAR measurements for obtaining atmospheric magnetic fields are discussed. The depolarization of Na and Ca lines are suitable for measuring magnetic fields in and near Io.

*S30* **N93-28794** / 160740  
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**RESOLUTION-ENHANCED MAPPING SPECTROMETER.** J. B. Kumer, J. N. Aubrun, W. J. Rosenberg, and A. E. Roche, Lockheed Palo Alto Research Laboratory, Palo Alto CA 94304, USA.

A familiar mapping spectrometer implementation utilizes two-dimensional detector arrays with spectral dispersion along one direction and spatial along the other. Spectral images are formed by spatially scanning across the scene (i.e., push-broom scanning). For imaging grating and prism spectrometers the slit is perpendicular to the spatial scan direction. For spectrometers utilizing linearly variable focal-plane-mounted filters the spatial scan direction is perpendicular to the direction of spectral variation. These spectrometers share the common limitation that the number of spectral

resolution elements is given by the number of pixels along the spectral (or dispersive) direction. In this presentation we discuss resolution enhancement by first passing the light input to the spectrometer through a scanned etalon or Michelson. Thus, while a detector element is scanned through a spatial resolution element of the scene, it is also temporally sampled. For example, to enhance resolution by a factor of 4 in a given spectral element, one would design the etalon to have finesse 4 in that spectral region, scan the etalon through a free spectral range as the detector is spatially scanned through spatial resolution element, and take eight samples in the process. To plug numbers in a specific example, suppose the mapping spectrometer pixel at 1  $\mu\text{m}$  had unenhanced resolution of 60  $\text{cm}^{-1}$ , but 15  $\text{cm}^{-1}$  resolution is desired. Further assume that 2 s is required to scan across a spatial element. An etalon with gap 83.33  $\mu\text{m}$  would give it the required free spectral range of 60  $\text{cm}^{-1}$ , reflectivity 46.5% would give it the required finesse  $\approx 4$ , and a sample rate of eight per second while scanning the gap through 1/2 wavelength (i.e., 0.5  $\mu\text{m}$  in this example, in order to scan through the 60  $\text{cm}^{-1}$  free spectral range) in eight steps of 0.5  $\mu\text{m}/8$  would provide a spectrum of resolution of 15  $\text{cm}^{-1}$  resolution within the order sorting 60  $\text{cm}^{-1}$  provided by the unenhanced spectrometer. Our presentation will address the analysis for all the pixels in the dispersive direction. We will discuss several specific examples. We will also discuss the alternate use of a Michelson for the same enhancement purpose. Suitable for weight constrained deep space missions, we have developed hardware systems including actuators, sensors, and electronics such that low-resolution etalons with performance required for implementation (performance requirement typified by the example above) would weigh less than one pound.

**PROPOSAL FOR A UNIVERSAL PARTICLE DETECTOR EXPERIMENT.** J. C. Lesho, R. P. Cain, and O. M. Uy, APL, Building 13-5377, Johns Hopkins University, Laurel MD 20723, USA.

The Universal Particle Detector Experiment (UPDE), which consists of parallel planes of two diode laser beams of different wavelengths and a large surface metal oxide semiconductor (MOS) impact detector, is proposed. It will be used to perform real-time monitoring of contamination particles and meteoroids impacting the spacecraft surface with high resolution of time, position, direction, and velocity. The UPDE will discriminate between contaminants

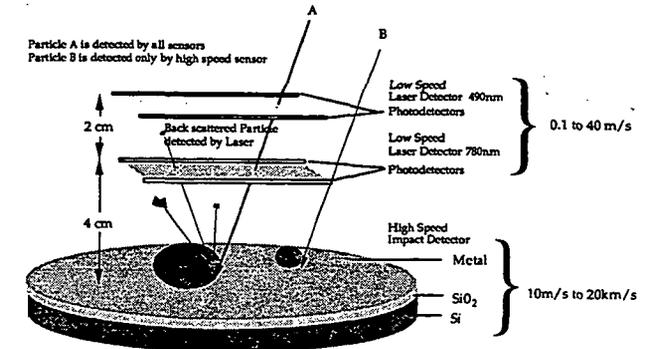


Fig 1. UPDE sensor.

and meteoroids, and will determine their velocity and size distributions around the spacecraft environment. With two different color diode lasers, the contaminant and meteoroid composition will also be determined based on laboratory calibration with different materials. Secondary particles dislodged from the top aluminum surface of the MOS detector will also be measured to determine the kinetic energy losses during energetic meteoroid impacts. The velocity range of this instrument is 0.1 m/s to more than 14 km/s, while its size sensitivity is from 0.2  $\mu\text{m}$  to millimeter-sized particles.

The particulate measurements in space of the kind proposed here will be the first simultaneous multipurpose particulate experiment that includes velocities from very slow to hypervelocities, sizes from submicrometer- to pellet-sized diameters, chemical analysis of the particulate composition, and measurements of the kinetic energy losses after energetic impacts of meteoroids.

This experiment will provide contamination particles and orbital debris data that are critically needed for our present understanding of the space environment. The data will also be used to validate contamination and orbital debris models for predicting optimal configurations of future space sensors and for understanding their effects on sensitive surfaces such as mirrors, lenses, paints and thermal blankets.

5N 93-28796 160742

**OPTIMISM EXPERIMENT AND DEVELOPMENT OF SPACE-QUALIFIED SEISMOMETERS IN FRANCE.** P. Lognonné<sup>1</sup>, J. F. Karczewski<sup>2</sup>, and DT/INSU-CRG Garchy Team<sup>2</sup>, <sup>1</sup>IPGP, 4 Place Jussieu, 75252 Paris Cedex 05, France, <sup>2</sup>INSU, 4 Avenue de Neptune, 94107 Saint Maur des Fosses Cedex, France.

The OPTIMISM experiment will put two magnetometers and two seismometers on the martian floor in 1995, within the framework of the Mars '94 mission. The seismometers are put within the two small surface stations.

The seismometer sensitivity will be better than  $10^{-9}$  g at 1 Hz, 2 orders of magnitude higher than the Viking seismometer sensitivity. *A priori* waveform modeling for seismic signals on Mars [1] shows that it will be sufficient to detect quakes with a seismic moment greater than  $10^{15}$  Nm everywhere on Mars. Such events, according to the hypothesis of a thermoelastic cooling of the martian lithosphere, are expected to occur at a rate close to one per week [2] and may therefore be observed within the 1-year lifetime of the experiment.

Due to severe constraints on the available power, mass budget, g load, and size of the small stations, it was necessary to completely redesign the seismometer sensors and electronic. The sensor has been developed in order to support a high g load of 200 g/10 ms without reducing its sensitivity. It consists of a new leaf-spring vertical seismometer, with a free period close to 0.5 s and an inertial mass of 50 g. The seismometer has two modes, working either with a velocity transducer, for high-frequency seismic measurements, or with a displacement transducer, for long-period seismic measurements. The seismometer's mass is 340 g, and its size is 9 cm<sup>3</sup>.

Along the same lines, a low-power, hybrid technology has been used for the electronic. The velocity transducer and displacement transducer need a power of a few milliwatts, with a sensitivity of  $10^{-10}$  for the displacement transducer.

This seismometer will be the first space-qualified or automatic very-broad-band seismometer to be developed in France. The next generation will consist of a triaxial seismometer, with performances

at least 1 order of magnitude better than the OPTIMISM seismometer.

**References:** [1] Lognonné and Mosser (1992). [2] Solomon et al. (1991).

N 93-28797 160743

**FILTERING INTERPOLATORS FOR IMAGE COMPARISON ALGORITHMS.** R. L. Lucke<sup>1</sup> and A. D. Stocker<sup>2</sup>, <sup>1</sup>Code 7604, Naval Research Laboratory, Washington DC 20375-5352, USA, <sup>2</sup>Space Computer Corporation, Suite 104, 2800 Olympic Boulevard, Santa Monica CA 90404-4119, USA.

Comparing two or more images, either by differencing or ratioing, is important to many remote sensing problems. Because the pixel sample points for the images are (almost) always separated by some nonzero shift, a resampling, or interpolation, process must be performed if one image is to be accurately compared to another. Considered in Fourier space, an interpolator acts as a filter that attenuates some frequencies (usually high) of the image. Thus, when the shifted and unshifted images are compared, the former has been filtered, while the latter has not; the effect of this difference is called interpolation error. The key idea of this paper is to apply a filter to the unshifted image that matches the filtering effect of applying the interpolator to the shifted image, thereby drastically reducing interpolation error. The resulting interpolators, called filtering interpolators, are derived and discussed in detail elsewhere [1]. Basic results will be given in this presentation.

The cost of reducing interpolation error is some loss of high-frequency information. This paper presents parameterized families of local convolutional interpolators (polynomial and trigonometric) that can be adjusted to the desired trade-off between interpolation error reduction and high-frequency information retention. These interpolators allow as many images as desired, all with different shifts, to be compared on an equal footing.

The method is derived for images with the same pixel spacing and purely translational shifts. Performance suffers if these conditions are not met, but is still better than ordinary interpolation. Four-point interpolators are probably the most useful because they give good interpolation performance with reasonable computational efficiency. One-dimensional formulas are given; for two dimensions, the interpolators are applied to each dimension separately. In tests on simulated imagery, the filtering interpolators reduced interpolation error to below the level of sensor noise for 13-bit data (LSB = rms noise) on highly structured scenes.

**References:** [1] Lucke R. L. and Stocker A. D. (1993) *IEEE Trans. Signal Processing*, in press.

534-91 N 93-28798 160744

**MASS SPECTROMETRIC MEASUREMENT OF MARTIAN KRYPTON AND XENON ISOTOPIC ABUNDANCE.** P. Mahaffy<sup>1</sup> and K. Mauersberger<sup>2</sup>, <sup>1</sup>Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt MD 20771, USA, <sup>2</sup>University of Minnesota, School of Astronomy and Physics, Minneapolis MN 55455, USA.

The Viking gas chromatograph mass spectrometer experiment provided significant data on the atmospheric composition at the surface of Mars, including measurements of several isotope ratios. However, the limited dynamic range of this mass spectrometer resulted in marginal measurements for the important Kr and Xe

isotopic abundance. The  $^{129}\text{Xe}$  to  $^{132}\text{Xe}$  ratio was measured with an uncertainty of 70%, but none of the other isotope ratios for these species were obtained. Accurate measurement of the Xe and Kr isotopic abundance in this atmosphere provides a important data point in testing theories of planetary formation and atmospheric evolution. The measurement is also essential for a stringent test for the martian origin of the SNC meteorites, since the Kr and Xe fractionation pattern seen in gas trapped in glassy nodules of an SNC (EETA 79001) is unlike any other known solar system reservoir. Current flight mass spectrometer designs combined with the new technology of a high-performance vacuum pumping system show promise for a substantial increase in gas throughput and the dynamic range required to accurately measure these trace species.

The wide dynamic range of present space flight mass spectrometer analyzer/detector systems allows ionization pressures to be pushed toward the point where the gas mean free path in the ion source is limiting. However, the fixed capacity of miniaturized high-vacuum pumping systems has put significant constraints on several previous mass spectrometer experiments, including the Viking mass spectrometer. The noble gases are not pumped by chemical pumps and with a very limited capacity by miniaturized ion pumps. In addition, an ion-pumped system can release previously pumped material with a corresponding loss of accuracy.

A recent commercial development in high-vacuum pumping technology is that of wide-range turbomolecular/molecular drag pump hybrids where both stages are attached to the same rotating shaft. The natural exhaust pressure of the molecular drag stage is approximately 10 mbar. Compression ratios of  $10^7$  or higher for N are achieved with very small pumping systems. It is expected that with continued development toward a ruggedized flight pump a mass of less than 1 kg for a system with a pumping speed of 10 to 30 liters/s can readily be achieved. The pump capacity is only limited by power constraints and eventual failure of the bearings after several thousand hours of operation. With reference to the payload described by the MESUR Science Definition Team, a mass spectrometer experiment incorporating such a pump together with a recently developed thermal analyzer [1] could provide information on the volatile composition of martian near-surface solid-phase material in addition to carrying out the isotope measurements described.

References: Mauersberger K. et al. (1992) *LPITech. Rpt. 92-07*.

**VISIBLE IMAGING ON THE PLUTO FAST FLYBY MISSION.** M. C. Malin, Malin Space Science Systems, 3535 General Atomics Court, Suite 250, San Diego CA 92121, USA:

Objectives for visible imaging of the Pluto-Charon system, as prescribed by the Outer Planets Science Working Group, are to acquire (1) global observations (FOV of ~5000 IFOVs) at 1 km/line-pair for the purpose of characterizing surface morphology and geology, (2) global observations in 3-5 broadband colors at 5-10 km/line-pair for studies of surface properties and composition as it relates to morphology, and (3) selected observations at higher spatial resolution for study of surface processes.

Several factors of the Pluto Fast Flyby mission make these difficult objectives to achieve: At Pluto's distance from the Sun, there is nearly 1/1000 the amount of light as at the Earth, the flyby

velocity is high (~15 km/s), and the science requirements dictate a large data volume (1 km/line-pair implies between 20 and 50 MBytes for the panchromatic global image, and a comparable amount for the multispectral dataset).

The low light levels can be addressed through a large aperture, image intensification, long exposures with precision pointing and image motion compensation (scan mirror or spacecraft movement), or time-delay integration. The high flyby velocities require short exposures, image motion compensation, or observations from considerable distance (e.g., longer focal lengths and larger apertures). Large data volume requires a large spacecraft data buffer, an internal instrument data buffer, or real-time data compression. The difficulty facing the successful Pluto Fast Flyby imaging investigation will be overcoming these technical challenges within the extremely limited mass (~2 kg) and power (~2 W) available.

**93-2-28800 160746**  
**A DTA/GC FOR THE *IN SITU* IDENTIFICATION OF THE MARTIAN SURFACE MATERIAL.** R. L. Mancinelli<sup>1</sup>, M. R. White<sup>1</sup>, and J. B. Orenberg<sup>2</sup>, <sup>1</sup>NASA Ames Research Center, Moffett Field CA 94035, USA, <sup>2</sup>Department of Chemistry and Biochemistry, San Francisco State University, San Francisco CA 94132, USA.

The composition and mineralogy of the martian surface material remain largely unknown. To determine its composition and mineralogy several techniques are being considered for *in situ* analyses of the martian surface material during missions to Mars. These techniques include X-ray fluorescence, X-ray diffraction,  $\alpha$ -proton backscattering,  $\gamma$  ray spectrometry, mass spectrometry, differential thermal analysis (DTA), differential scanning calorimetry (DSC), and pyrolysis gas chromatography. Results of a comparative study of several of these techniques applicable to remote analysis during MESUR-class missions indicate that DTA/GC would provide the most revealing and comprehensive information regarding the mineralogy and composition of the martian surface material [1].

We have successfully developed, constructed, and tested a laboratory DTA/GC. The DTA is a Dupont model 1600 high-temperature DTA coupled with a GC equipped with a MID detector. The system is operated by a Sun Sparc II workstation. When gas evolves during a thermal chemical event, it is shunted into the GC and the temperature is recorded in association with the specific thermal event. We have used this laboratory instrument to define experimental criteria necessary for determining the composition and mineralogy of the martian surface *in situ* (e.g., heating of sample to 1100°C to distinguish clays). Our studies indicate that DTA/GC will provide a broad spectrum of mineralogical and evolved gas data pertinent to exobiology, geochemistry, and geology. Some of the important molecules we have detected include organics (hydrocarbons, amides, amines, etc.),  $\text{CO}_3^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ ,  $\text{SO}_4^{2-}$ ,  $\text{H}_2\text{O}$ , and  $\text{CO}_2$ . The technique can also discern the mineral character of the sample (i.e., clay vs. silicates vs. glasses; degrees of hydration, etc.) [2]. It is thought that the surface of Mars consists primarily of an amorphous juvenile silicate material similar to palagonite with not more than 15 wt% clay [3]. This type of mixture is easily determined by DTA/GC using the high-temperature (1100°C) capability of the DTA [1,2]. This is important to the definition of mission analytical techniques, which must be able to analyze samples ranging from those containing no clay or evaporites to samples composed of

significant amounts of highly structured clay and evaporites within a predominately amorphous matrix.

**References:** [1] Schwartz D. E. et al. (1993) *Adv. Space Res.*, 13, in press. [2] Mancinelli R. L. et al. (1992) *LPSC XXIII*, 831-832. [3] Orenberg J. B. and Handy J. (1992) *Icarus*, 96, 219-225.

**93-288047 160747**  
**ONBOARD SIGNAL PROCESSING: WAVE OF THE FUTURE FOR PLANETARY RADIO SCIENCE?** E. A. Marouf, Department of Electrical Engineering, San Jose State University, San Jose CA 95192-0084, USA.

Future spacecraft-based radio observations of planetary surfaces, rings, and atmospheres could significantly benefit from recent technological advances in real-time digital signal processing (DSP) hardware. Traditionally, the radio observations have been carried out in a "downlink" configuration in which about 20-W spacecraft-transmitted RF power illuminates the target of interest and the perturbed signal is collected at an Earth receiving station. The downlink configuration was dictated by the large throughput of received data, corresponding to a relatively large recording band width (about 50 kHz) needed to capture the coherent and scattered signal components in the presence of trajectory, ephemeris, and measurement uncertainties. An alternative "uplink" configuration in which powerful Earth-based radio transmitters (20-200 kW) are used to illuminate the target and data are recorded onboard a spacecraft could enhance the measurements' signal-to-noise ratio by a factor of about 1000, allowing a quantum leap in scientific capabilities. The recorded data must be preprocessed to reduce its volume while preserving its salient information content. The latter include time-history of estimates of the amplitude and phase of the coherent signal and dynamic power spectra of the scattered signal, computed at adaptable resolutions. The "compressed" data is later relayed to the Earth for further detailed processing and analysis. Onboard data compression can readily be accomplished either by a DSP processor that is a part of an Uplink Radio Science Instrument, or by a configurable spacecraft "DSP subsystem" that serves as a preprocessing engine for multiple spacecraft instruments. In either case, the hardware architecture must be sufficiently flexible to allow implementation of a broad class of preprocessing algorithms, adaptable to a given observation geometry and corresponding signal dynamics. Specific signal compression needs and expected scientific gain are illustrated for potential future uplink observation of planetary ring systems. A similar argument can be made for radio observations of the tenuous atmosphere of Pluto and for radio imaging of the martian surface, two potential-targets for the Pluto FFM and the Mars MESUR missions.

**93-288047 160748**  
**SPACEBORNE PASSIVE RADIATIVE COOLER.** S. Mathias, Arthur D. Little, Inc., Cambridge MA 02140, USA.

Radiative coolers are passive refrigeration devices for satellites and space probes that provide refrigeration for an infrared or other type of detector that operates at cryogenic temperatures. Typically a cooler can supply 20 mW of cooling at about 85 K, and over 500 mW of cooling at about 165 K. The exact cooler temperatures and heat loads are dependent upon the clear field of view of the cooler to space.

Some features of the Arthur D. Little passive radiative cooler are (1) the cooler has no moving parts leading to very long life and high reliability; (2) the cooler weight is approximately 3 lb; (3) the detector may be easily replaced without disassembling the cooler; (4) the alignment of the detector is insensitive to induced launch vibration and thermal cycling; (5) a movable field lens provides a simple method of adjusting the system focus during testing at operating temperatures; (6) the optical axis is referenced to the room-temperature mounting flange interface, eliminating the need for iterative optical adjustments in thermal vacuum chambers at the system level; (7) heater and temperature sensors provide precise detector temperature control; (8) the design offers protection against overheating of the sensitive detector element during nonoperational spacecraft attitude acquisition; (9) a modular "bolt-on" concept provides simple integration and interface definition of the cooler with an optical system; and (10) there is maximum protection of the low-temperature optical elements from contamination.

**93-288037 160749**  
**SYSTEMATIC PROCESSING OF CLEMENTINE DATA FOR SCIENTIFIC ANALYSES.** A. S. McEwen, U.S. Geological Survey, Flagstaff AZ 86001, USA.

If fully successful, the Clementine mission will return about 3,000,000 lunar images and more than 5000 images of Geographos. Effective scientific analyses of such large datasets require systematic processing efforts. Described below are concepts for two such efforts.

**Global Multispectral Imaging of the Moon:** The lunar orbit has been designed to enable global coverage with the UV/VIS and near-IR cameras. Global coverage will require 120 frames per orbit x 300 orbits x 16 frames (6 near-IR filters and double coverage in 5 UV/VIS filters to improve S:N), for a total of 576,000 image frames. Lunar scientists cannot analyze half a million small images. We will need a single global 11-wavelength image cube with full geometric and radiometric calibrations and photometric normalizations. Processing steps could include (1) decompressing the data, (2) radiometric calibration, (3) removal of camera distortions, (4) co-registration of each set of 16 images to 0.2 pixel, (5) replacing bad or missing data, (6) merging UV/VIS double coverage, (7) identifying three control points per orbit, (8) along-track frame matching (geometry and brightness), (9) reprojecting images, (10) photometric function normalization, (11) mosaicking into single-orbit strips, (12) brightness matching of orbit strips, and (13) mosaicking orbit strips into map quadrangles. The final global dataset at a scale of 100 m/pixel will require a set of 70 CD-ROMS (650 Mbytes/CD) for archiving and distribution. Once systematic processing is completed, a series of global maps can be derived that show the distribution and abundances of pyroxenes, olivine, anorthosite, shocked anorthosite, norite, troctolite, glassy materials, and titanium.

**Videos of Geographos:** Clementine is expected to acquire continuous imaging throughout the closest approach sequence at Geographos with frame rates of 4.5 or 9 frames/s. (For comparison, the highest frame rate on Galileo is 0.4 frame/s, and there was no imaging near closest approach to Gaspra.) The high frame rates and continuous imaging are ideal for production of computer "movies" of the flyby, which can be recorded onto video tapes. These movies

will consist of actual observations, rather than simulated sequences generated from a shape model. They will enable the viewer to see all the details of the topography, morphology, and distribution of compositional units as the viewing and illumination geometries change. Several different video sequences of Geographos are anticipated, including separate sequences for each imaging system and merged datasets. The LIDAR will provide the highest spatial resolutions (in four colors), the thermal-IR detector will provide nightside imaging, the UV/VIS camera will provide the highest resolution of the entire visible and illuminated surface during the 75 s before and after closest approach, and the UV/VIS plus near-IR detectors will map the mineralogy.

**SOURCES SOUGHT FOR INNOVATIVE SCIENTIFIC INSTRUMENTATION FOR SCIENTIFIC LUNAR ROVERS.** C. Meyer, Solar System Exploration Division, Mail Code SN2, NASA Johnson Space Center, Houston TX 77058, USA.

Lunar rovers should be designed as integrated scientific measurement systems that address scientific goals as their main objective. Scientific goals for lunar rovers are (1) to develop a more complete understanding of the stratigraphy, structure, composition, and evolution of the lunar crust by close examination of the geology and geochemistry of multiple, wide-spaced landing sites on the Moon; (2) to improve the understanding of the lunar regolith and history of solar system events that have affected the lunar surface; (3) to improve the understanding of the lunar interior and set constraints on planetary evolution using geophysical techniques; and (4) to identify and characterize potential lunar "resources" that could be utilized by future human missions.

Teleoperated robotic field geologists will allow the science team to make discoveries using a wide range of sensory data collected by electronic "eyes" and sophisticated scientific instrumentation. Rovers need to operate in geologically interesting terrain (rock outcrops) and to identify and closely examine interesting rock samples. Analytical instrumentation should measure the maturity of soils and the chemical composition (major, minor, and trace) and mineralogy of soils and fresh surfaces of rock samples. Some ingenious method is needed to obtain fresh rock surfaces. Manipulator arms are needed to deploy small close-up cameras and lightweight instruments, such as alpha backscatter spectrometers, as "stethoscopes" to the clasts in boulders. Geoscience missions should also deploy geophysical packages.

Enough flight-ready instruments are available to fly on the first mission, but additional instrument development based on emerging technology is desirable. There are many interesting places to explore on the Moon (i.e., the lunar poles) and it is highly desirable to fly multiple missions with continuously improved instrument sets. For example, there are needs for (1) *in situ* reflectance spectroscopy measurements (with high spectral resolution TBD) to determine the spectra (~0.3-2.5 μm) and mineral contents of rocks and soils in a manner analogous to what is done from a distance by Earth-based telescopes or from lunar orbit; (2) Mössbauer spectroscopy to determine soil maturity and mineralogy and relative abundance of iron-bearing phases; (3) close-up images by a "field-lens" electronic camera with artificial lighting and good depth focus (autofocus?) allowing scientists in the control room to have the

ability to make discoveries and document what has been analyzed by the analytical instruments; (4) precise and accurate analytical measurements of the chemical composition of soils and rocks—especially the critical determination of the Fe/Mg ratio and one or more of the large ion lithophile elements; (5) cryogenic systems to cool solid-state detectors such as infrared sensitive CCD arrays, Si(Li) X-ray or Ge gamma ray detectors; (6) multispectral imagery by CCD cameras including telephoto, metric, or panoramic; (7) bore-sited laser range-finding equipment with gimbals that read out angles for precise site survey; and (8) thermally evolved gas analysis.

**DRILL/BORESCOPE SYSTEM FOR THE MARS POLAR PATHFINDER.** D. A. Paige, S. E. Wood, and A. R. Vasavada, Department of Earth and Space Sciences, University of California, Los Angeles CA 90024, USA.

The primary goals of the Mars Polar Pathfinder (MPP) Discovery mission are to characterize the composition and structure of Mars' north polar ice cap, and to determine whether a climate record may be preserved in layers of ice and dust. The MPP would land as close as possible to the geographic north pole of Mars and use a set of instruments similar to those used by glaciologists to study polar ice caps on Earth: a radar sounder, a drill/borescope system, and a thermal probe. The drill/borescope system will drill ~50 cm into the surface and image the sides of the hole at 10-μm resolution for compositional and stratigraphic analysis.

Several uncertainties have guided the development of this instrument. It is presently not known whether the surface at the north pole consists of solid ice or packed snow, or how difficult it will be to drill. In order to more quantitatively investigate design and power requirements, we built a thermal chamber for testing the drill/borescope instruments under Mars-like conditions with complete remote control. To minimize the number of mechanisms and moving parts, an integrated drill/borescope system would be desirable for the MPP. However, for these initial tests we used separate off-the-shelf components: a Hilti model TE-10A rotary percussion drill, and an ITI 26-in rigid borescope attached to a Sony XC-999 cigar-type color CCD camera. The drill rotates at about 500 rpm while hammering at about 50 Hz, using about 150 W. Using a 1-in continuous-flute drill bit, it is able to drill through 12 in of -80°C solid ice in about two minutes, with no down-force applied except for its own weight. A talus pile of the low-density shavings forms around the surface, but the hole is left clear after the drill is retracted. The borescope is a hard-optics right-angled device with fiber-optic illumination at its tip. It is able to focus from near contact to infinity. The borescope has a 13° vertical field of view, which amounts to about 3 mm of vertical distance at the viewing distance in our 1-in-diameter holes. This equipment, and high-resolution vertical scans of two boreholes, are part of a videotape. We prepared three types of samples: pure ice, ice with dust layers, and snow with dust layers. To make the ice/dust sample we successively poured and froze a suspension of 2-μm cinder particles in water. The dust settles as the water freezes, and forms layers between clear ice. The first close-up images of the inside of a hole were taken in the solid ice/dust sample with the borescope as it is lowered slowly to the bottom. The ice in these images appears almost black, and the dust layers are reddish

N93-28804 160750 p.1  
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one drilled

Various instruments that are now to be developed for later missions will be described



*S493-283708 160754*

**INFRARED RUGATES BY MOLECULAR BEAM EPI-TAXY.** M. Rona, Arthur D. Little, Inc., Cambridge MA 02140, USA.

*P-1*  
Rugates are optical structures that have a sinusoidal index of refraction (harmonic gradient-index field). As their discrete high/low index filter counterparts, they can be used as narrow rejection band filters. However, since rugates do not have abrupt interfaces, they tend to have a smaller absorption, hence deliver a higher in-band reflectivity. The absence of sharp interfaces makes rugates even more desirable for high-energy narrowband reflectors. In this application, the lack of a sharp interface at the maximum internal standing wave electric field results in higher breakdown strengths.

Our method involves fabricating rugates, with molecular beam epitaxy [1], on GaAs wafers as an  $\text{Al}(x)\text{Ga}(1-x)\text{As}$  single-crystal film in which  $x$ , the alloying ratio, changes in a periodic fashion between  $0 < x < 0.5$  [2]. The single-crystal material improves the rugate performance even further by eliminating the enhanced optical absorption associated with the grain boundaries. Salient features of our single-crystal rugate fabrication program, including the process control system and methodology and some representative results, are shown [3].

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*S45 N93-28809 160755*

**PLASMA, MAGNETIC, AND ELECTROMAGNETIC MEASUREMENTS AT NONMAGNETIC BODIES.** C. T. Russell and J. G. Luhmann, Institute of Geophysics and Planetary Physics, University of California, Los Angeles CA 90024-1567, USA.

*P-1*  
The need to explore the magnetospheres of the Earth and the giant planets is widely recognized and is an integral part of our planetary exploration program. The equal need to explore the plasma, magnetic, and electromagnetic environments of the nonmagnetic bodies is not so widely appreciated. The previous, albeit incomplete, magnetic and electric field measurements at Venus, Mars, and comets have proven critical to our understanding of their atmospheres and ionospheres in areas ranging from planetary lightning to solar wind scavenging and accretion. In the cases of Venus and Mars, the ionospheres can provide communication paths over the horizon for low-altitude probes and landers, but we know little about their lower boundaries. The expected varying magnetic fields below these planetary ionospheres penetrates the planetary crusts and can be used to sound the electrical conductivity and hence the thermal profiles of the interiors. However, we have no knowledge of the levels of such fields, let alone their morphology. Finally, we note that the absence of an atmosphere and an ionosphere does not make an object any less interesting for the purposes of electromagnetic exploration. Even weak remanent magnetism such as that found on the Moon during the Apollo program provides

insight into the present and past states of planetary interiors. We have very intriguing data from our space probes during times of both close and distant passages of asteroids that suggest they may have coherent magnetization. If true, this observation will put important constraints on how the asteroids formed and have evolved. Our planetary exploration program must exploit its full range of exploration tools if it is to characterize the bodies of the solar system thoroughly. We should especially take advantage of those techniques that are proven and require low mass, low power, and low telemetry rates to undertake.

*S46 N93-28810 160756 P-1*

**A COMPACT IMAGING DETECTOR OF POLARIZATION AND SPECTRAL CONTENT.** D. M. Rust, A. Kumar, and K. E. Thompson, Applied Physics Laboratory, The Johns Hopkins University, Johns Hopkins Road, Laurel MD 20723, USA.

A new type of image detector will simultaneously analyze the polarization of light at all picture elements in a scene. The Integrated Dual Imaging Detector (IDID) consists of a polarizing beam splitter bonded to a charge-coupled device (CCD), with signal-analysis circuitry and analog-to-digital converters, all integrated on a silicon chip. The polarizing beam splitter can be either a Ronchi ruling, or an array of cylindrical lenslets, bonded to a birefringent wafer. The wafer, in turn, is bonded to the CCD so that light in the two orthogonal planes of polarization falls on adjacent pairs of pixels. The use of a high-index birefringent material, e.g., rutile, allows the IDID to operate at f-numbers as high as  $f/3.5$ .

Without an auxiliary processor, the IDID will output the polarization map of a scene with about 1% precision. With an auxiliary processor, it should be capable of  $1:10^4$  polarization discrimination. The IDID is intended to simplify the design and operation of imaging polarimeters and spectroscopic imagers used, for example, in planetary, atmospheric and solar research. Innovations in the IDID include (1) two interleaved  $512 \times 1024$ -pixel imaging arrays (one for each polarization plane), (2) large dynamic range (well depth of  $10^6$  electrons per pixel), (3) simultaneous read-out of both images at 10 million pixels per second each, (4) on-chip analog signal processing to produce polarization maps in real time, and (5) on-chip 10-bit A/D conversion. When used with a lithium-niobate Fabry-Perot etalon or other color filter that can encode spectral information as polarization, the IDID can collect and analyze simultaneous images at two wavelengths. Precise photometric analysis of molecular or atomic concentrations in the atmosphere is one suggested application.

*S47 N93-28811 160757 P-2*

**DIGITAL IMAGE COMPRESSION USING ARTIFICIAL NEURAL NETWORKS.** M. Serra-Ricart<sup>1</sup>, Ll. Garrido<sup>2,3</sup>, V. Gaitan<sup>2</sup>, and A. Aloy<sup>4</sup>, <sup>1</sup>Instituto de Astrofísica de Canarias, E-38200 La Laguna (Tenerife), Spain, <sup>2</sup>Departament d'Estructura i Constituents de la Matèria, Universitat de Barcelona, Diagonal 647, E-08028 Barcelona, Spain, <sup>3</sup>Institut de Física d'Altes Energies, Universitat Autònoma de Barcelona, E-08193 Bellaterra (Barcelona), Spain, <sup>4</sup>Digital Equipment Enterprise Espana SA., Provenza, 204-208, 08036 Barcelona, Spain.

The problem of storing, transmitting, and manipulating digital images is considered. Because of the file sizes involved, large amounts of digitized image information are becoming common in

modern projects. Transmitting images will always consume large amounts of bandwidth, and storing images will always require special devices. Our goal is to describe an image compression transform coder based on artificial neural networks techniques (hereafter Neural Network Compression Transform Coder or NNCTC). Like all generic image compression transform coders, the NNCTC embodies a three-step algorithm: invertible transformation to the image (transform), lossy quantization (quantize), and entropy coding (remove redundancy). Efficient algorithms have already been developed to achieve the two last steps, quantize and remove redundancy [4]. The NNCTC offers an alternative invertible transformation based on neural network analysis [3].

A comparison of the compression results obtained from digital astronomical images by the NNCTC and the method used in the compression of the digitized sky survey from the Space Telescope Science Institute based on the H-transform [3] is performed in order to assess the reliability of the NNCTC.

Artificial neural network techniques are based on the dot-product calculation, which is very simple to perform in hardware [4]. It is in this sense that the NNCTC can be useful when high compression and/or decompression rates are required (e.g., space applications, remote observing, remote database access).

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N93-28812 160758

**PROTOTYPE BACKSCATTER MÖSSBAUER SPECTROMETER FOR MESUREMENT OF MARTIAN SURFACE MINERALOGY.** T. D. Shelfer<sup>1</sup>, R. V. Morris<sup>1</sup>, D. G. Agresti<sup>2</sup>, T. Nguyen<sup>3</sup>, E. L. Wills<sup>2</sup>, and M. H. Shen<sup>2</sup>, <sup>1</sup>Code SN4, NASA Johnson Space Center, Houston TX 77058, USA, <sup>2</sup>Physics Department, University of Alabama at Birmingham, Birmingham AL 35294, USA, <sup>3</sup>Lockheed Engineering and Sciences Co., Houston TX 77058, USA.

We have designed and successfully tested a prototype of a backscatter Mössbauer spectrometer (BaMS) targeted for use on the martian surface to (1) determine oxidation states of iron and (2) identify and determine relative abundances of iron-bearing mineralogies. No sample preparation is required to perform measurements; it is only necessary to bring sample and instrument into physical contact. The prototype meets our projected specifications for a flight instrument in terms of mass (<500 g), power (<2 W), and volume (<300 cm<sup>3</sup>).

A Mössbauer spectrometer on the martian surface would provide a wide variety of information about the current state of the martian surface:

1. **Oxidation state:** Iron Mössbauer spectroscopy (FeMS) can determine the distribution of iron among its oxidation states. Is soil oxidized relative to rocks?

2. **Mineralogy:** FeMS can identify iron-bearing mineralogies (e.g., olivine, pyroxene, magnetite, hematite, ilmenite, clay, and amorphous phases) and their relative abundances. FeMS is not blind to opaque phases (e.g., ilmenite and magnetite), as are visible and near-IR spectroscopy.

3. **Magnetic properties:** FeMS can distinguish between magnetite and maghemite, which are putative mineralogies to explain

the magnetic nature of martian soil.

4. **Water:** FeMS can distinguish between anhydrous phases such as hematite, olivine, pyroxene, and hydrous phases such as clay, ferrihydrite, goethite, and lepidocrocite. What are the relative proportions of hydrous and anhydrous iron-bearing mineralogies?

In summary, a BaMS instrument on MESUR would provide a very high return of scientific information about the martian surface (with no sample preparation) and would place a very low resource demand (weight, power, mass, data rate) on spacecraft and lander. Our BaMS instrument can be flight-qualified within two years and is also suitable for lander missions to the Moon, comets, and asteroids.

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N93-28813 160759 P-1

**SPACECRAFT COMPUTER TECHNOLOGY AT SOUTHWEST RESEARCH INSTITUTE.** D. J. Shirley, Southwest Research Institute, San Antonio TX 78228-0510, USA.

Southwest Research Institute (SwRI) has developed and delivered spacecraft computers for a number of different near-Earth-orbit spacecraft including shuttle experiments and SDIO free-flyer experiments. Here we describe the evolution of the basic SwRI spacecraft computer design from those weighing in at 20 to 25 lb and using 20 to 30 W to newer models weighing less than 5 lb and using only about 5 W, yet delivering twice the processing throughput. Because of their reduced size, weight, and power, these newer designs are especially applicable to planetary instrument requirements. The basis of our design evolution has been the availability of more powerful processor chip sets and the development of higher-density packaging technology, coupled with more aggressive design strategies in incorporating high-density FPGA technology and use of high-density memory chips. In addition to reductions in size, weight, and power, the newer designs also address the necessity of survival in the harsh radiation environment of space. Spurred by participation in such programs as MSTI, LACE, RME, Delta 181, Delta Star, and RADARSAT, our designs have evolved in response to program demands to be small, low-powered units, radiation tolerant enough to be suitable for both Earth-orbit microsats and for planetary instruments. Present designs already include MIL-STD-1750 and Multi-Chip Module (MCM) technology with near-term plans to include RISC processors and higher-density MCMs. Long-term plans include development of whole-core processors on one or two MCMs.

N93-28814 160760

**THE BACKGROUNDS DATA CENTER.** W. A. Snyder<sup>1</sup>, H. Gursky<sup>1</sup>, H. M. Heckathorn<sup>1</sup>, R. L. Lucke<sup>1</sup>, S. L. Berg<sup>2</sup>, E. G. Dombrowski<sup>3</sup>, and R. A. Kessel<sup>2</sup>, <sup>1</sup>Code 7604, Naval Research Laboratory, Washington DC 20375-5352, USA, <sup>2</sup>Computational Physics, Inc., Suite 600, 2750 Prosperity Avenue, Fairfax VA 22031, USA, <sup>3</sup>Sachs-Freeman Associates, 1401 McCormick Drive, Landover MD 20785, USA.

The Strategic Defense Initiative Organization (SDIO) has created data centers for midcourse, plumes, and backgrounds

phenomenologies. The Backgrounds Data Center (BDC), located at the Naval Research Laboratory (NRL), has been designated by the SDIO as the prime archive for data collected by SDIO programs for which substantial backgrounds measurements are planned. The BDC will be the prime archive for MSX data, which will total about 15 TB over three years. Current BDC holdings include data from the VUE, UVPI, UVLIM, FUVCAM, TCE, and CLOUDS programs. Data from IBSS, CIRRI 1A, and MSTI, among others, will be available at the BDC in the near future. The BDC will also archive data from the Clementine mission.

The BDC maintains a Summary Catalog that contains "metadata," that is, information about data, such as when the data were obtained, what the spectral range of the data is, and what region of the Earth or sky was observed. Queries to this catalog result in a listing of all datasets (from all experiments in the Summary Catalog) that satisfy the specified criteria. Thus, the user can identify different experiments that made similar observations and order them from the BDC for analysis. On-site users can use the Science Analysis Facility (SAF) for this purpose.

For some programs, the BDC maintains a Program Catalog, which can classify data in as many ways as desired (rather than just by position, time, and spectral range as in the Summary Catalog). For example, datasets could be tagged with such diverse parameters as solar illumination angle, signal level, or the value of a particular spectral ratio, as long as these quantities can be read from the digital record or calculated from it by the ingest program. All unclassified catalogs and unclassified data will be remotely accessible.

The activities and functionality of the BDC will be described. Information is presented about the BDC facilities, user support capabilities, and hardware and software systems.

**N93-28815**  
 551-91 ABS-ONLY 160761

**THE ENHANCED-MODE LADAR WIND SENSOR AND ITS APPLICATION IN PLANETARY WIND VELOCITY MEASUREMENTS.** D. C. Soreide, R. L. McGann, L. L. Erwin, and D. J. Morris, Boeing Defense and Space Group, Seattle WA 98124, USA.

For several years we have been developing an optical air-speed sensor that has a clear application as a meteorological wind-speed sensor for the Mars landers. This sensor has been developed for airplane use to replace the familiar, pressure-based Pitot probe. Our approach utilizes a new concept in the laser-based optical measurement of air velocity (the Enhanced-Mode Ladar), which allows us to make velocity measurements with significantly lower laser power than conventional methods.

The application of the Enhanced-Mode Ladar to measuring wind speeds in the martian atmosphere has a number of advantages over previously fielded systems. The point at which the measurement is made is approximately 1 m from the lander. This eliminates the problem of flow distortion caused by the lander. Because the ladar uses a small, flush-mounted window in the lander instead of being mounted out in the wind, dust damage and erosion will be dramatically reduced. The calibration of the ladar system is dependent only on the laser wavelength, which is inherently fixed. Our approach does require the presence of aerosol particles, but the presence of dust in the martian atmosphere is well established. Preliminary calculations indicate that the Enhanced-Mode Ladar will only

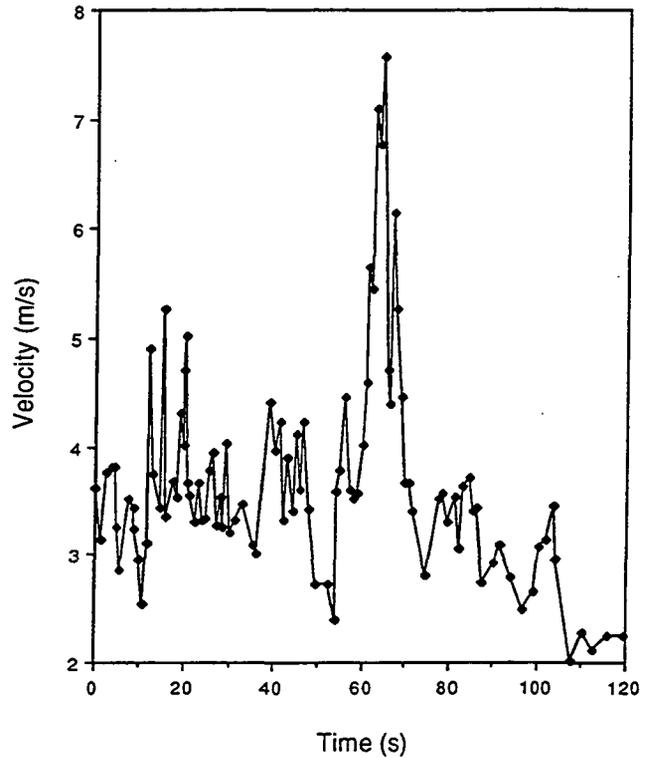


Fig. 1. Wind speed vs. time backscatter coefficient = 4.5E-6.

consume 0.001 Ws per velocity update, not including the power for signal processing. We have developed a brassboard version of the Enhanced-Mode Ladar for airplane applications that we will flight test in early April. This brassboard has been used to measure wind speeds (in Earth's atmosphere) with a backscatter coefficient similar to that on Mars. Results of a single set of measurements are shown in Fig. 1.

**N93-28816**  
 552-91 ABS-ONLY 160762 P-2

**THE MESUR MISSION.** S. W. Squyres, Center for Radio-physics and Space Research, Cornell University, Ithaca NY 14853, USA.

The MESUR mission is the most ambitious mission to Mars planned by NASA for the coming decade. It will place a network of small, robust landers on the martian surface, making a coordinated set of observations for at least one full martian year. The mission addresses two main classes of scientific objectives. The first requires a large number of simultaneous observations from widely distributed sites. These include establishing networks of seismic and meteorological stations that will yield information on the internal structure of the planet and the global circulation of the atmosphere respectively. The second class of objectives requires sampling as much as possible the full diversity of the planet. These include a variety of geochemical measurements, imaging of surface morphology, and measurement of upper atmospheric properties at a range of latitudes, seasons, and times of day.

MESUR presents some major challenges for development of instruments, instrument deployment systems, and onboard data processing techniques. The instrument payload has not yet been selected, but the strawman payload is (1) a three-axis seismometer; (2) a meteorology package that senses pressure, temperature, wind speed and direction, humidity, and sky brightness; (3) an alpha-proton-X-ray spectrometer (APXS); (4) a thermal analysis/evolved gas analysis (TA/EGA) instrument; (5) a descent imager; (6) a panoramic surface imager; (7) an atmospheric structure instrument (ASI) that senses pressure, temperature, and acceleration during descent to the surface; and (8) radio science. Because of the large number of landers to be sent (about 16), all these instruments must be very lightweight. All but the descent imager and the ASI must survive landing loads that may approach 100 g. The meteorology package, seismometer, and surface imager must be able to survive on the surface for at least one martian year. The seismometer requires deployment off the lander body. The panoramic imager and some components of the meteorology package require deployment above the lander body. The APXS must be placed directly against one or more rocks near the lander, prompting consideration of a microrover for deployment of this instrument. The TA/EGA requires a system to acquire, contain, and heat a soil sample. Both the imagers and, especially, the seismometer will be capable of producing large volumes of data, and will require use of sophisticated data compression techniques.

However, instead of one long flight tube it consists of a series of cylindrical electrostatic lenses that confine ions under study along the axis of the flight tube. This results in a short flight tube (i.e., low mass), high mass resolution, and high energy resolution. A laboratory version of this instrument is in routine operation. A schematic diagram of this instrument is shown in Fig. 1.

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**PLUTO FAST FLYBY MISSION AND SCIENCE OVERVIEW.** A. Stern, Space Science Department, Southwest Research Institute, 6220 Culebra Road, San Antonio TX 78238, USA.

Planning for the Pluto Fast Flyby (PFF) mission centers on the launch of two small (110-160 kg) spacecraft late in the 1990s on fast, 6-8-year trajectories that do not require Jupiter flybys. The cost target of the two-spacecraft PFF mission is \$400 million. Scientific payload definition by NASA's Outer Planets Science Working Group (OPSWG) and JPL design studies for the Pluto flyby spacecraft are now being completed, and the program is in Phase A development. Selection of a set of lightweight, low-power instrument demonstrations is planned for May 1993. According to plan, the completion of Phase A and then detailed Phase B spacecraft and payload design work will occur in FY94. The release of an instrument payload AO, followed by the selection of the flight payload, is also scheduled for FY94. I will describe the scientific rationale for this mission, its scientific objectives, and give an overview of the spacecraft and strawman payload.

**A LOW-COST, LIGHTWEIGHT, AND MINIATURIZED TIME-OF-FLIGHT MASS SPECTROMETER (TOFMS).** S. K. Srivastava, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

Time-of-flight mass spectrometers (TOFMS) are commonly used for mass analysis and for the measurement of energy distributions of charged particles. For achieving high mass and energy resolution these instruments generally comprise long flight tubes, often as long as a few meters. This necessitates high voltages and a very clean environment. These requirements make them bulky and heavy. We have developed [1] an instrument and calibration techniques [2] that are based on the design principles of TOFMS.

**VENUS INTERIOR STRUCTURE MISSION (VISM): ESTABLISHING A SEISMIC NETWORK ON VENUS.** E. R. Stofan<sup>1</sup>, R. S. Saunders<sup>1</sup>, D. Senske<sup>1</sup>, K. Nock<sup>1</sup>, D. Tralli<sup>1</sup>, P. Lundgren<sup>1</sup>, S. Smrekar<sup>1</sup>, B. Banerdt<sup>1</sup>, W. Kaiser<sup>1</sup>, J. Dudenhoefer<sup>2</sup>, B. Goldwater<sup>3</sup>, A. Schock<sup>4</sup>, and J. Neuman<sup>5</sup>, <sup>1</sup>Jet Propulsion Laboratory, Pasadena CA 91109, USA, <sup>2</sup>Lewis Research Center, Cleveland OH, USA, <sup>3</sup>Mechanical Technology Inc., Latham NY, USA, <sup>4</sup>Fairchild Space, Germantown MD, USA, <sup>5</sup>Martin Marietta, Denver CO, USA.

**Introduction:** Magellan radar data show the surface of Venus to contain a wide range of geologic features (large volcanos, extensive rift valleys, etc.) [1,2]. Although networks of interconnecting zones of deformation are identified, a system of spreading ridges and subduction zones like those that dominate the tectonic style of the Earth do not appear to be present. In addition, the absence of a mantle low-viscosity zone suggests a strong link between mantle dynamics and the surface [3,4]. As a natural follow-on to the Magellan mission, establishing a network of seismometers on Venus will provide detailed quantitative information on the large-scale interior structure of the planet. When analyzed in conjunction with image, gravity, and topography information, these data will aid in constraining mechanisms that drive surface deformation.

**Scientific Objectives:** The main objective for establishing a network of seismometers on Venus is to obtain information on both

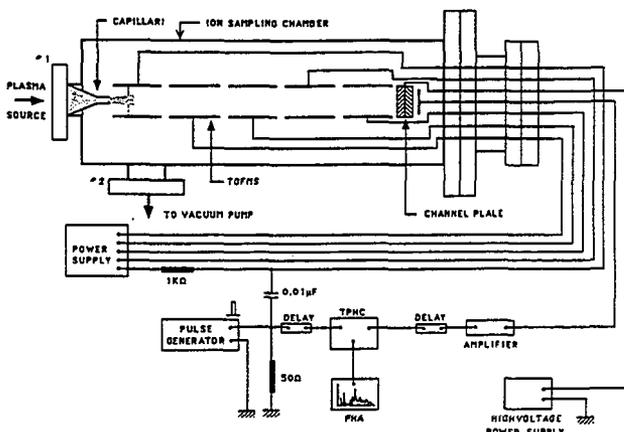


Fig. 1. Schematic diagram of the ion mass sensor.

shallow and deep structure of the planet. Problems that will be specifically addressed are (1) identifying the location of the crust/mantle boundary, (2) determining the presence or absence of a mantle low-viscosity zone, (3) establishing the state of the core (is there a liquid outer core?), (4) measuring the spatial and temporal distribution of Venus quakes, and (5) determining source mechanisms for Venus quakes.

**Mission Structure:** The Venus Interior Structure Mission (VISM) consists of three seismometers deployed from landers on the surface in a triangular pattern (two located approximately 250 km from each other and the third at the apex of the triangle at a distance of 1000 km). The landers will be delivered by a carrier bus that will be placed into Venus orbit so it can act as relay to transmit data from the surface to the Earth (data rate of 100 Mb/day/lander). By necessity, the surface stations must be relatively long-lived, on the order of six months to one year. In order to achieve this goal, each lander will employ a General Purpose Heat Source (GPHS)-powered Stirling engine to provide cooling (refrigeration to 25°C) and electric power. Upon reaching the surface, a seismometer is deployed a small distance from each lander and is directly coupled to the surface. Seismic data are recorded at a rate of 1100 b/s (including lander engineering telemetry). The seismometer will be enshrouded by a shield so as to isolate it from wind noise. The instrument is an accelerometer patterned after that proposed for MESUR, having a sensitivity in the range of 0.05 Hz to 40 Hz. On the basis of theoretical analyses, it should be possible to observe over 600 events of magnitude 4.0 or better over the lifetime of the network, which will provide sufficient data to characterize the large-scale interior structure of Venus.

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56N-93-28820/160766

**PLASMA DIAGNOSTICS BY ANTENNA IMPEDANCE MEASUREMENTS.** C. M. Swenson, K. D. Baker, E. Pound, and M. D. Jensen, Space Dynamics Laboratory, Utah State University, Logan UT 84322, USA.

The impedance of an electrically short antenna immersed in a plasma provides an excellent *in situ* diagnostic tool for electron density and other plasma parameters. By electrically short we mean that the wavelength of the free-space electromagnetic wave that would be excited at the driving frequency is much longer than the physical size of the antenna. Probes using this impedance technique have had a long history with sounding rockets and satellites, stretching back to the early 1960s [1]. This active technique could provide information on composition and temperature of plasmas for comet or planetary missions.

There are several advantages to the impedance probe technique when compared with other methods. The measurement of electron density is, to first order, independent of electron temperature, vehicle potential, probe surface contamination, and orientation to the geomagnetic field. Surface heating and variations of the antenna surface physics do not effect the VLF and RF characteristics of the antenna and hence do not effect the accuracy of the measurements. As such, the technique is ideal for probes plunging into

planetary atmospheres where surface contamination is a concern.

Currently two classes of instruments are built and flown by SDL-USU for determining electron density, the so-called capacitance and plasma frequency probes. The plasma frequency probe [7] operates in nearly collisionless plasmas and can provide absolute electron density measurements with 1% accuracy at sampling rates as high as 20 kHz, and the capacitance probe can provide electron density measurements with about 5% accuracy in strongly collisional plasmas. The instrumentation weighs less than 0.5 kg, consumes less than 1 W (continuous operation), and only requires a simple 0.1-m antenna [4]. Recently, from 1987 to 1991, the plasma frequency probe has successfully flown on 11 sounding rockets launched into the Earth's ionosphere at low, mid, and high latitudes and 5 more are being readied for missions in the immediate future.

The impedance of such short antennas has been extensively studied theoretically [2,3,5] and laboratory experiments have shown excellent agreement with theory [6]. When the current distribution on the antenna matches a natural mode of the plasma, energy is carried away by a plasma wave resulting in a large contribution to the antenna impedance. A measurement of the antenna impedance provides information on the normal modes of a plasma from which electron density, temperature, or ion composition could be deduced. The versatility and simplicity of an impedance probe would be ideal for the limited resources of planetary missions.

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56N-93-28821/160767 P-2

**LUNAR SCIENCE: USING THE MOON AS A TESTBED.** G. J. Taylor, Planetary Geosciences, Department of Geology and Geophysics, SOEST, University of Hawaii, 2525 Correa Road, Honolulu HI 96822, USA.

The Moon is an excellent testbed for innovative instruments and spacecraft. Excellent science can be done, the Moon has a convenient location, and previous measurements have calibrated many parts of it. I summarize these attributes and give some suggestions for the types of future measurements.

**Lunar Science:** The Lunar Scout missions planned by NASA's Office of Exploration will not make all the measurements needed. Thus, test missions to the Moon can also return significant scientific results, making them more than technology demonstrations.

**Location:** The Moon is close to Earth, so cruise time is insignificant, tracking is precise, and some operations can be controlled from Earth, but it is in the deep space environment, allowing full tests of instruments and spacecraft components.

**Calibrations:** The existing database on the Moon allows tests of new instruments against known information. The most precise data come from lunar samples, where detailed analyses of samples from a few places on the Moon provide data on chemical and mineralogical composition and physical properties. Apollo field excursions provided *in situ* measurement of surface geotechnical

properties and local magnetic field strength. Orbital data obtained by Apollo missions also supply a useful set of standards, although not global in extent; data include chemical composition by gamma and X-ray spectrometry, imaging, and magnetic field strength. Observations at high spectral resolution have been obtained from terrestrial telescopes, providing spectral calibration points for numerous 1–5-km spots on the lunar surface. Finally, additional multispectral imaging has been obtained by the Galileo spacecraft and a global multispectral dataset will be acquired by the Clementine mission. Thus, the Moon is a large, Earth-orbiting standard on which to test new instruments.

**Potential Instruments:** The following list shows examples of the types of instruments that could take advantage of the Moon's virtues as a testbed. Lunar Scout I and II do not include items 1–4. Items 5–7 are thus essential if Scout does not fly, but even if Scout is successful, new generations of these instruments (smaller, better resolution, etc.) can still use the global database obtained by Scout as calibrations. (1) Atmospheric sensors, such as UV spectrometers and mass spectrometers. (2) Magnetic field detectors, such as magnetometers and electron reflectometers. (3) Altimeters for topography measurements. (4) Microwave radiometers, especially for heat flow determination. (5) Imaging spectrometers to obtain mineralogical information about the Moon. (6) Imaging systems for geologic mapping. (7) Devices to make chemical analyses from orbit-present instruments, such as gamma ray spectrometers (these are currently large and heavy, so new, smaller devices are essential for future planetary missions).

**In Situ Analyses:** Excellent lunar science could be done using rovers carrying experimental payloads. Possible instruments include devices to do chemical and mineralogical analyses, high-resolution stereo imaging systems, gas analyzers, seismometers, heat flow probes, and atmospheric sensors.

**USE OF PARTICLE BEAMS FOR LUNAR PROSPECTING.**  
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A key issue in choosing the appropriate site for a manned lunar base is the availability of resources, particularly oxygen and hydrogen for the production of water, and ores for the production of fuels and building materials. NASA has proposed two Lunar Scout missions that would orbit the Moon and use, among other instruments, a hard X-ray spectrometer, a neutron spectrometer, and a Ge gamma ray spectrometer to map the lunar surface. This passive instrumentation will have low resolution (tens of kilometers) due to the low signal levels produced by natural radioactivity and the interaction of cosmic rays and the solar wind with the lunar surface. This paper presents the results of a concept definition effort for a neutral particle beam lunar mapper probe. The idea of using particle beam probes to survey asteroids was first proposed by Sagdeev et al. [1], and an ion beam device was fielded on the 1988 Soviet probe to the Mars moon Phobos. During the past five years, significant advances in the technology of neutral particle beams (NPB) have led to a suborbital flight of a neutral hydrogen beam device in the SDIO-sponsored BEAR experiment. An orbital experiment, the Neutral Particle Beam Far Field Optics Experiment (NPB-FOX) is presently in the preliminary design phase. The development of NPB

accelerators that are space-operable leads one to consider the utility of these devices for probing the surface of the Moon using gamma ray, X-ray, and optical/UV spectroscopy to locate various elements and compounds [2]. We consider the utility of the NPB-FOX satellite containing a 5-MeV particle beam accelerator as a probe in lunar orbit. Irradiation of the lunar surface by the particle beam will induce secondary and backscattered radiation from the lunar surface to be detected by a sensor that may be co-orbital with or on the particle beam satellite platform, or may be in a separate orbit. The secondary radiation is characteristic of the make-up of the lunar surface. The size of the spot irradiated by the beam is less than 1 km wide along the groundtrack of the satellite, resulting in the potential for high resolution. The fact that the probe could be placed in polar orbit would result in global coverage of the lunar surface. The orbital particle beam probe could provide the basis for selection of sites for more detailed prospecting by surface rovers.

This work was partially supported by the U.S. Army Strategic Defense Command under Contract No. DASG60-90-C-0103, Grumman Corporation Subcontract # 52-87979.

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**SUBNANORADIAN, GROUND BASED TRACKING OF SPACEBORNE LASERS.** R. N. Treuhaft, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

Over the next few decades groundbased tracking of lasers on planetary spacecraft will supplement or replace tracking of radio transponders. This paper describes research on two candidate technologies for groundbased, angular, laser tracking: the infrared interferometer and the optical filled-aperture telescope. The motivation for infrared and optical tracking will be followed by a description of the current (10–50 nanoradian) and future (sub-nanoradian) stellar tracking demonstrations with the University of California-Berkeley Infrared Spatial Interferometer (ISI) on Mt. Wilson [1], and the University of California-San Diego Optical Ronchi Telescope on Table Mountain [2].

In the long term, lasers will replace radio transponders to increase telemetry data rates, roughly tenfold, by communication over optical channels [3]. In the short term (next 10 years), few-nanoradian tracking of a low-power laser may outperform single-frequency radio tracking. For example, radio tracking at 3-cm wavelengths is afflicted by charged particle fluctuations at the 5–10 nanoradian level; charged particle effects are negligible for infrared and optical frequencies. Tracking of low-power lasers at planetary distances seems feasible with the above-mentioned instruments. For example, a 0.5-W laser through a 10-cm aperture at Mars could be tracked by both of the above instruments, with modest upgrades to be implemented before this spring-summer observing season.

Angular tracking interferometric phase-time series from ISI will be discussed. It will be shown that new hardware, which will improve detector efficiency, will enable reliable cycle ambiguity resolution in moderate seeing. High correlations between measurements of path lengths within ISI, and those along the paths through

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the atmosphere to the target star, suggest that most of the atmospheric turbulence contributing to poor seeing is occurring within about 10 m of the ground. For the Table Mountain Ronchi telescope, signal-to-noise improvements will enable tracking of a visual magnitude 11 star. Demonstrations of this capability will occur this summer after hardware upgrades in the spring.

The above demonstrations will yield 10–50-nanoradian performance, but it has been shown that subnanoradian performance enables many mission enhancements. For example, subnanoradian angular tracking enables detection of Jupiter's spacecraft-relative position about 100 days before encounter. Subnanoradian tracking is largely prevented by atmospheric refractivity fluctuations for both the above mentioned devices. Methods of minimizing atmospheric effects using optimal stochastic estimation and direct calibration will be described.

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*560-91 N93-2882460770*  
*P.1*  
**A TEAM APPROACH TO THE DEVELOPMENT OF GAMMA RAY AND X-RAY REMOTE SENSING AND *IN SITU* SPECTROSCOPY FOR PLANETARY EXPLORATION MISSIONS.** J. I. Trombka<sup>1</sup> (Team leader), S. Floyd<sup>1</sup>, A. Ruitberg<sup>1</sup>, L. Evans<sup>2</sup>, R. Starr<sup>3</sup>, A. Metzger<sup>4</sup>, R. Reedy<sup>5</sup>, D. Drake<sup>5</sup>, C. Moss<sup>5</sup>, B. Edwards<sup>5</sup>, L. Franks<sup>6</sup>, T. Devore<sup>6</sup>, W. Quam<sup>6</sup>, P. Clark<sup>7</sup>, W. Boynton<sup>8</sup>, A. Rester<sup>9</sup>, P. Albats<sup>10</sup>, J. Groves<sup>10</sup>, J. Schweitzer<sup>11</sup>, and M. Mahdavi<sup>11</sup>, <sup>1</sup>Goddard Space Flight Center, Greenbelt MD 20771, USA, <sup>2</sup>Computer Sciences Corporation, Calverton MD 20705, USA, <sup>3</sup>The Catholic University of America, Washington DC 20064, USA, <sup>4</sup>Jet Propulsion Laboratory, Pasadena CA 91109, USA, <sup>5</sup>Los Alamos Scientific Laboratory, Los Alamos NM 87545, USA, <sup>6</sup>EG & G Energy Measurements Santa Barbara, Goleta CA 93117, USA, <sup>7</sup>Albright College, Reading PA 19612, USA, <sup>8</sup>University of Arizona, Tucson AZ 85721, USA, <sup>9</sup>University of Florida, Alachua FL 32615, USA, <sup>10</sup>Schlumberger-Doll Research, Ridgefield CT 06877, USA, <sup>11</sup>EMR Schlumberger, Princeton NJ 08542, USA.

An important part of the investigation of planetary origin and evolution is the determination of the surface composition of planets, comets, and asteroids. Measurements of discrete line X-ray and gamma ray emissions from condensed bodies in space can be used to obtain both qualitative and quantitative elemental composition information.

Remote sensing X-ray and gamma ray spectrometers aboard either orbital or flyby spacecraft can be used to measure line emissions in the energy region ~0.2 keV to ~10 MeV. These elemental characteristic excitations can be attributed to a number of processes such as natural radioactivity, solar X-ray fluorescence, and cosmic ray primary- and secondary-induced activity. Determination of composition for the following elements can be expected: O, Si, Fe, Mg, Ti, Ca, H, Cl, K, Th, and U. Global elemental composition maps can be obtained using such spectrometer systems.

More complete elemental composition can be obtained by landing packages that include X-ray and gamma ray spectrometer systems along with X-ray, charged particle, and neutron excitation sources on planetary surface. These *in situ* systems can be used on stationary, roving, and penetrator missions. Both the remote sensing and *in situ* spectrometer systems have been included aboard a number of U.S. and Russian planetary missions [1,2].

The Planetary Instrument Definition and Development Program (PIDDP) X-Ray/Gamma Ray Team has been established to develop X-ray and gamma ray remote sensing and *in situ* technologies for future planetary exploration missions. This team represents groups having active programs with NASA, the Department of Energy (DOE), the Department of Defense (DOD), and a number of universities and private companies. A number of working groups have been established as part of this research program. These include groups to study X-ray and gamma ray detectors, cryogenic cooling systems, X-ray and particle excitation sources, mission geochemical research requirements, detector space radiation damage problems, field simulation studies, theoretical calculations and X-ray and nuclear cross sections requirements, and preliminary design of flight systems. Major efforts in this program will be devoted to the development of X-ray/gamma ray remote sensing systems for the NEAR (Near Earth Asteroid Rendezvous) mission and for *in situ* X-ray and gamma ray/neutron systems for penetrators, soft landers, and rovers for MESUR missions.

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*P.2*  
**MINIATURE LONG-LIFE SPACE CRYOCOOLERS.** E. Tward, TRW, One Space Park, Redondo Beach CA 90278, USA.

Cryogenic coolers for use in space on small satellites require low power and minimum weight. The need for exceptional reliability in a space cooler is made even more critical on small satellites since cooler redundancy is often not an option due to weight constraints. In this paper we report on two reliable, small, efficient low-power, vibrationally balanced coolers designed specifically for use on small satellites.

TRW has designed, built, and tested a miniature integral Stirling cooler and a miniature pulse tube cooler intended for long-life space application. Both efficient, low-vibration coolers were developed for cooling IR sensors to temperatures as low as 50 K on lightsats.

The vibrationally balanced nonwearing design Stirling cooler incorporates clearance seals maintained by flexure springs for both the compressor and the drive displacer. The design achieved its performance goal of 0.25 W at 65 K for an input power to the compressor of 12 W. The cooler recently passed launch vibration tests prior to its entry into an extended life test and its first scheduled flight in 1995.

The vibrationally balanced, miniature pulse tube cooler intended for a 10-year long-life space application incorporates a nonwearing flexure bearing compressor vibrationally balanced by a motor-controlled balancer and a completely passive pulse tube cold head. The maximum cooling power measured at 80 K is 800 mW for an input power to the compressor of 30 W. The cooler is suitable for cooling sensors and optics between 60 K and 200 K, with cooling

powers up to 3.5 W at 200 K. Self-induced vibration measurements indicate that the cooler can be balanced to reduce vibration forces below 0.02 newtons from 0 to 500 Hz.

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**ENVIRONMENTAL MONITORS IN THE MIDCOURSE SPACE EXPERIMENTS (MSX).** O. M. Uy, Applied Physics Laboratory, The Johns Hopkins University, Laurel MD 20723, USA.

The Midcourse Space Experiment (MSX) is an SDIO-sponsored spacebased sensor experiment with a full complement of optical sensors. Because of the possible deleterious effect of both molecular and particulate contamination on these sensors, a suite of environmental monitoring instruments are also being flown with the spacecraft. These instruments are the Total Pressure Sensor based on the cold-cathode gauge, a quadrupole mass spectrometer, a Bennett-type ion mass spectrometer, a cryogenic quartz crystal microbalance (QCM), four temperature-controlled QCMs, and a Xenon and Krypton Flash Lamp Experiment. These instruments have been fully space-qualified, are compact and low cost, and are possible candidate sensors for near-term planetary and atmospheric monitoring. The philosophy of adopted during design and fabrication, calibration and ground testing, and modeling will be discussed.

opportunity to obtain composition information from spectra at those wavelengths. We propose construction of a flight instrument functioning in the 1100–3200-Å spectral range that is suitable for a dedicated satellite (“QuickStar”) or as a space-station-attached payload. It can also be an autonomous package in the space shuttle cargo bay.

The instrument structure is of graphite fiber epoxy composite, and has an objective diffraction grating, low expansion optics, multichannel plate electro-optics, and event discrimination capability through processing of video data. It would either have a field-of-view (fov) of 12° and f number of 0.75 or a wider fov of 20°–25° and f number of 1. The instrument has a heritage from the UV auroral imager of the Swedish Viking spacecraft [4].

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**N93-28828** 160774  
**DEVELOPMENT OF MINIATURIZED OPTIMIZED SMART SENSORS (MOSS) FOR SPACE PLASMAS.** D. T. Young, Southwest Research Institute, Instrumentation and Space Research Division, San Antonio TX 78228-0510, USA.

The cost of space plasma sensors is high for several reasons: (1) Most are one-of-a-kind and state-of-the-art, (2) the cost of launch to orbit is high, (3) ruggedness and reliability requirements lead to costly development and test programs, and (4) overhead is added by overly elaborate or generalized spacecraft interface requirements. Possible approaches to reducing costs include development of small “sensors” (defined as including all necessary optics, detectors, and related electronics) that will ultimately lead to cheaper missions by reducing (2), improving (3), and, through work with spacecraft designers, reducing (4). Despite this logical approach, there is no guarantee that smaller sensors are necessarily either better or cheaper. We have previously [1] advocated applying analytical “quality factors” to plasma sensors (and spacecraft) and have begun to develop miniaturized particle optical systems by applying quantitative optimization criteria. We are currently designing a Miniaturized Optimized Smart Sensor (MOSS) in which miniaturized electronics (e.g., employing new power supply topology and extensive use of gate arrays and hybrid circuits) are fully integrated with newly developed particle optics to give significant savings in volume and mass. The goal of the SwRI MOSS program is development of a fully self-contained and functional plasma sensor weighing ~1 lb and requiring ~1 W. MOSS will require only a typical spacecraft DC power source (e.g., 30 V) and command/data interfaces in order to be fully functional, and will provide measurement capabilities comparable in most ways to current sensors.

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**N93-28829** 160775  
**X-RAY, FAR, AND EXTREME ULTRAVIOLET COATINGS FOR SPACE APPLICATIONS.** M. Zukic and D. G. Torr, Physics Department, University of Alabama in Huntsville, Huntsville AL 35899, USA.

**N93-28827** 160773

**ULTRAVIOLET IMAGING SPECTROMETER.** T. J. Wdowiak, Department of Physics, University of Alabama at Birmingham, CH 310, 1300 University Blvd., Birmingham AL 35294-1170, USA.

Wide-field imaging systems equipped with objective prisms or gratings have had a long history of utility in groundbased observations of meteors [1] and comets [2]. Deployment of similar instruments from low Earth orbit would allow the first UV observations of meteors. This instrument can be used for comets and Lyman alpha coroneae of Earth-orbit-crossing asteroids. A CaF<sub>2</sub> prism imaging spectrograph designed for stellar observations was used aboard Skylab to observe Comet Kohoutek (1973f), but its 1300-Å cut-off precluded Lyman alpha images and it was not used for observation of meteors [3]. Because the observation of the UV spectrum of a meteor has never been attempted, researchers are denied the

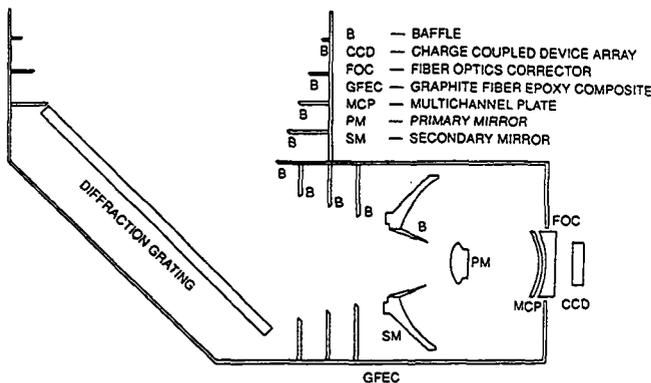


Fig. 1.

The improved FUV filters that we have designed and fabricated

were made as combinations of three reflection and one transmission filter. Narrowband filtering with a bandwidths of 5 nm and a throughput at the central wavelength of more than 20% is achieved, for example, at 130.4 nm and 135.6 nm with the average blocking of out-of-band wavelengths of better than  $4 \times 10^{-4}\%$ . In the case of broadband filters a multiple reflector centered at 150 and 170 nm combined with corresponding transmission filters had a bandwidth of more than 11 nm and transmittance greater than 60%. The average blocking of out-of-band wavelengths is better than  $4 \times 10^{-4}\%$  with less than  $10^{-5}\%$  transmittance at 121.6 nm [1-5]. The idea of utilizing the multiple reflections from  $\Pi$  multilayer reflectors constitutes the basis of the design approach used for the narrowband and broadband filters. The multiple reflector combinations provide spectral performance for narrow- and broadband filters superior to what was previously available [6-9].

The idea of utilizing imaging mirrors as narrowband filters constitutes the basis of the design of extreme ultraviolet imagers operating at 58.4 nm and 83.4 nm. The net throughput of both imaging-filtering systems is better than 20%. The superiority of the EUV self-filtering camera/telescope becomes apparent when compared to previously theoretically designed 83.4-nm filtering-imaging systems, which yielded transmissions of less than a few percent [10] and therefore less than 0.1% throughput when combined with at least two imaging mirrors. Utilizing the self-filtering approach,

instruments with similar performances are possible for imaging at other EUV wavelengths, such as 30.4 nm [11-12].

The self-filtering concept is extended to the X-ray region where its application can result in the new generation of X-ray telescopes, which could replace current designs based on large and heavy collimators. The calculated reflectance for an  $80^\circ$  angle of incidence shows a reflectance peak value of 35.8% at 0.73 nm (2.621 KeV) with the bandwidth of the reflector less than 0.01 nm. The in-band to out-band ratio is more than 3000, with an instrument monochromatic sensitivity factor  $T[\%]\Delta\lambda[\text{nm}] > 3600$ . At an  $85^\circ$  angle of incidence the peak reflectance is more than 65% at 0.44 nm with a bandwidth of less than 0.006 nm providing the ratio  $T[\%]\Delta\lambda[\text{nm}] > 10,000$ .

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